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PROCEEDINGS

Mr Jernej Cimpersek

EXPERT WORKSHOP ON EXPLOSIVE DETECTION TECHNIQUES FOR USE IN MINE CLEARANCE AND SECURITY RELATED REQUIREMENTS

2 – 4 JUNE 2003
BLED LAKE
SLOVENIA

Content

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Workshop Programme

02 June 2003

09:00 - 18:30	Workshop Registration at the reception desk of the GOLF HOTEL BLED	
20:00	*Reception hosted by ITF*	

03 June 2003

08:30 - 08:45	Jernej CIMPERŠEK, ITF (Slovenia)	Welcome on behalf of local organizers
08:45 - 09:00	Alois J. SIEBER, EC - JRC (Italy)	Welcome on behalf of the Organizing Committee
SESSION 1	**Chairman: Dick WEAVER**	
09:00 - 09:30	Hiltmar SCHUBERT, PSE GmbH (Germany)	Detection of explosives for terrorist-bombs and landmine clearance – Different applications of similar methods
09:30 - 09:45	Michel LEFEBVRE, RMA (Belgium)	Chemical and physical properties and the detection of home-made explosives
09:45 - 10:00	Louis WASSERZUG, TSWG, Special Operations Washington (USA)	Overview of technology development in explosive detection.
10:00 - 10:30		DISCUSSION. Conclusions Session 1
10:30 - 11:00		*Coffee Break*
SESSION 2	**Chairman: Marc ACHEROY**	
11:00 - 11:15	Petr MOSTAK (Czech Republic)	Detection of plastic explosives in explosive devices
11:15 - 11:45	Garth SHILSTONE, DSTL (UK)	Detection and Imaging with NQR, THz, and X-ray Techniques
11:45 - 12:00	Daniel VAN DER WEIDE, University of Wisconsin-Madison (USA)	THz detection of explosives and biologicals
12:0 - 12:15	John GILBERT, DSTL (UK)	Vapour detection and canine/bee olfaction
12:15 - 12:30	Christophe COX, APOPO (Belgium)	An Overview of the APOPO Program, rats for landmine detection
12:30 - 13:00		DISCUSSION. Conclusions Session 2
13:00 - 14:30		*Lunch Time*
SESSION 3	**Chairman: Ulf ROSENGÅRD**	
14:30 - 14:45	Richard LANZA, Massachusetts Institute of Technology (USA)	Neutron Resonance Radiography for Security Applications

14:45 - 15:00	Andrey KUTZENTSOV, V.G. Khlopin Radium Institute (Russia)	Portable multi-sensor for detection and identification of explosives substances
15:00 - 15:15	Israel HIRSCH, Aphelion Ltd. (Israel)	Practical aspects of using explosive detection techniques
15:15 - 15:30	Russel HARMON, U.S. Army Research Office (USA)	An emerging analytical technology for military and homeland defence applications
15:30 - 16:00		DISCUSSION. Conclusions Session 3
16:00 - 16:45		*Coffee break*
16:45 - 17:30	**Chairman: Alois J. Sieber**	**Open discussion**
19:00	*Welcome Dinner hosted by S. Zbogar, State Secretary at the Ministry of Foreign Affairs of the Republic of Slovenia*	

04 June 2003

SESSION 4	**Chairman: Garth SHILSTONE**	
09:00 - 09:30	Tomaz APIH; Robert BLINC Institute Jozef Stefan (Slovenia)	Detection of explosives by quadrupole resonance
09:30 - 09:45	Janko LUZNIK, IMFM (Slovenia)	Improvement of nitrogen NQR detection in explosives by proton polarization.
09:45 - 10:00	Vernon JOYNT, CSIR (South Africa)	Explosive detection in mine clearance: chemical behavior in the field
10:00 - 10:30		DISCUSSION. Conclusions Session 4
10:30 - 11:00		*Coffee break*
SESSION 5	**Chairman: Tomaz APIH**	
11:00 - 11:15	Michael KRAUSA, ICT (Germany)	Demands on chemical vapor detection of landmines and explosives for counter-terrorism
11:15 - 11:30	Ulf ROSENGÅRD, IAEA (Austria)	The IAEA coordinated research project on nuclear techniques for anti personnel landmine identification
11:30 - 11:45	Chris WEICKERT, CCMAT (Canada)	Imaging techniques (optical and infrared) in landmine detection
11:45 - 12:00	Lawrence CARIN, Duke University, Durham, NC, USA	New Developments in Coupling Radar, EMI and NQR for sensing anti-personnel land mines
12:00 - 12:45		DISCUSSION. Conclusions Session 5
12:45 - 14:30		*Lunch time*

ROUND-TABLE DISCUSSION	**Chairman: John REINGRUBER**

14:30 - 14:50		Current Capability, Current and Anticipated Requirements, Future Directions and Research Priorities.
14:50 - 16:00	Panelists John REINGRUBER Hiltmar SCHUBERT Garth SHILSTONE Daniel VAN DER WEIDE Ulf ROSENGÅRD	Discussions
19:30		*Workshop Banquet*

Conclusions of the expert workshop on explosive detection techniques for use in mine clearance and security related requirements

2 to 4 June 2003, at the Lake Bled, Republic of Slovenia

In spite of intensive efforts in the research and development of improved tools in the detection and identification of anti personal landmines, no advanced tool has yet been fielded. The use of metal detectors together with the use of dogs and mechanical devices are the present standard. A first prototype combining the detection of metal components (metal detector) and the search for anamolies (GPR) will pass in the very near future a systematic test phase. However, mine clearance could significantly benefit from the availability of a reliable device for the location explosive material. Moreover, it could become a key component in the context of countermeasures against terrorism and enhancing security of commercial aviation, container shipment, crucial infrastructure etc.

In order

- to assess similarities in the detection of landmines and countermeasures against terrorism,
- identify needs for further research and development, and
- for testing protocols and performance criteria

it the workshop was organized bringing together experts from the community of mine clearance, from counterterrorism, from organizations in charge of security of aviation, shipping of containers, etc and research and testing organizations.

The presentations and subsequent discussions have reached a consensus by all participants with the following conclusions:

- Terahertz technology seems to be very interesting for several applications like detection of explosives as well as biological bacteria; in order to be able to appreciate the full potential of this new technology it has been agreed to stimulate a systematic exploitation phase. It has been agreed to launch this process through an expert meeting which will be hosted by DSTL, UK in September 2003;
- This workshop has been regarded as one milestone which must have a follow up in order to assess progress made and to evaluate emerging technologies as well as needs. The participants agreed to reconvene in about two years time.

The discussions on the different needs and available technology are summerised in the following table:

CHECKPOINT PERSONNEL

Technology	Multi Sensor Combinations	Further Research/Actions
Canines		Odor Phenomenology
Microwave		prototype development
NQR	Trace Portal	Demonstration
Particle Detection		Improved Sampling, preconcentration, additional compounds
Rats		Pilot Operation
THz		Feasibility
Vapor Detection		Improved Sampling, preconcentration, additional compounds

CHECKPOINT VEHICLES

Technology		Further Research/Actions
Automatic / Colorimetric		Prototype
Neutron Activation	Combined with gammatransmission	Prototype
NQR		Prototype

STANDOFF PERSONNEL

Technology		Further Research/Actions
Canines		Training/Demonstration
MMW		Determine Potential
THz		Determine Potential
Vapor Detection		Determine Potential, signal processing
Acoustics		Determine Potential
		Time reversed acoustics
Thermal Imaging		Determine Potential
Vapor Detection		Improved Sampling, preconcentration, additional compounds

STANDOFF VEHICLES

Technology	Multi Sensor Combinations	Further Research/Actions
Neutron Activation	Plus Gamma	Prototype Development
NQR		Breadboard Demonstration
Rats		Breadboard radio rat
Gamma Ray		Demonstration
Vapor Detection		Improved Sampling, preconcentration, additional compounds

The workshop was also supported by the "Demining Technologies – International Forum (DTIF)". It was the fourth DTIF workshop and at the same time, the second one co-sponsored by the European Research Office (ERO).

Furthermore, it is requested that Conference literature acknowledges support by the U.S. Army Research Laboratory European Research Office, the U.S. Army Communications and Electronics Command Night Vision Laboratory, OSD, the U.S. Army Communications and Electronics Command European Research Office and the Office of Naval Research International Field Office.

Welcome on behalf of the local organisers
Goran GACNIK, Deputy Director ITF, Slovenia

Bled, 4 June 2003

A word from

Goran Gacnik, Deputy Director

When choosing the venue for the fourth Expert Workshop on the Explosive Detection Techniques for Use in Mine Clearance and Security Related Requirements the organizing committee decided for it to be Bled.

The International Trust Fund for Demining and Mine Victims Assistance took is an honor when asked to help to facilitate this, in our opinion very significant workshop, so we accepted it without hesitation.

It is my firm belief that the workshop proved very successful as it managed to bring together so many experts and consequently introduced the latest techniques and tools as well as research to help in the fight against the hidden killers, ie. landmines still contaminating in more than 60 countries around the world.

The presentations showed the efforts of the organizations as well as the individuals how important is supporting the cooperative relationships that could contribute to the common goals.

I hope that we provided good enough hospitality that you will decide to visit our country again not only by business but also as private. It will be our honor to host such an important event again and we hope to see you there.

Goran Gacnik
Deputy Director

Welcome on behalf of the organizing committee
Alois J. SIEBER, EC – JRC, Italy

Expert workshop on explosive detection techniques for use in mine clearance and security related requirements

Dr. Alois J. Sieber
Humanitarian Security Unit
Institute for the Protection & Security of the Citizen
Joint Research Centre, Ispra, Italy
European Commission

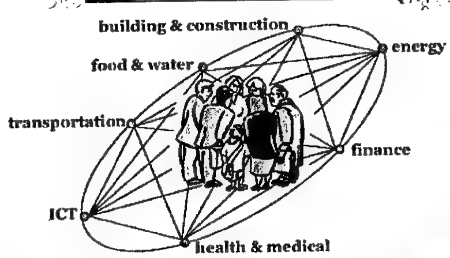
Content

- The problem & a possible definition
- Short list of topics
- Example 1: Container security
- Example 2: International crime
- Example 3: Weather forecast vs. terrorism
- A possible common systems approach
- Needs for actions

Observations

- The security of the citizen depends increasingly on the ability to handle non-military crisis.
- The vulnerability of modern society does not end at the boarder line of the country the citizen is living in.
- Every place of existence for every citizen is potentially under threat at any time.
- The living environment and any supply line of every citizen is potentially under threat at any time.

Aspects of Humanitarian Security



How to define HS ?

- JRC started with expert study on "Science and Technology in support to European Security"
  (ToR clearly specified non-military security aspects!)
- Study included an expert workshop at high level hosted by the Swedish Minister for Foreign Affaires
  (Stockholm, April 2002 - http://demining.jrc.it/aris/news/security_workshop/s-n-t-2002-0619.pdf)
- In consequence, JRC facilitated and is organizing a number of expert meetings and workshops, e. g. container security, detection of explosives

Security issue of potential relevance

- The vulnerability of the modern societies
  - Terrorism
  - International Crime, Drugs and Illegal Trafficking.
  - "Information warfare"
  - Disaster mitigation
- Non-proliferation of weapons of mass destruction: nuclear, chemical and biological
- Disarmament and arms control and confidence building measures

non-military threats to the security of societies and citizens in Europe

- Our ability to handle non-state actors on a global basis is key to our security
- Need for European leadership in preserving existing treaties and in finding new fora and new forms for multilateral arms control discussions.
- Prevent the proliferation of weapons of mass destruction.
- Threat from well organized crime is increasing and requires development of the national police forces and improved European police cooperation.

Workshop
Bled 2 & 4 June 2003 7

Cont.

- Threat from well organized crime is increasing and requires development of the national police forces and improved European police cooperation

Workshop
Bled 2 & 4 June 2003 8

Example

Container Security

Workshop
Bled 2 & 4 June 2003 9

Container Security - WS Conclusions

- 200 mio containers transported world wide p.y.
- 90 95% of world trade through containers
- major harbor ~ 15000 container in/out p.d.
- only 1 2% checked
- CS not existing today
- Stakeholders no incentive to implement security measures- besides 9/11
- today seals applied to establish liability

Workshop
Bled 2 & 4 June 2003 10

Container Security

Key stakeholders include:

- **shippers,**
- **shipping lines,**
- **consolidators,**
- **terminal operators,**
- **government and port authorities (at ports of loading and discharge) for different trade lanes,**
- **insurance companies,**
- **etc**

Workshop
Bled 2 & 4 June 2003 11

Container Security

Key Components

- **Scenarios & Assessment of Possible Impacts (Gaming)**
  +
- **Intelligence** (hard and soft intelligence; private and government; analyses)
  +
- **Shipment Profile and Information** (booking, cargo information, manufacturer, shipper, consignee)
  +
- **Container Tracking and Security Monitoring** (from packing to port of loading to port of discharge to final delivery)
  +
- **Intelligent Container** (reading of seals, sensors for detection, monitoring of in/out,etc)

Workshop
Bled 2 & 4 June 2003 12

Container Security

- Tasks
  - **to design, test and validate a complete system based on the key identified components**

    \+
  - **assess the possibility to detect explosive material hidden inside a container**

Problem

- After almost 10 years of work on the improvement of the detection and identification of landmines, only dogs are used to search for explosive components.

  ==> question ????

Questions

- Which technologies could be used to detect explosive materials, be inside landmines, containers, etc?
- What are the commonalties/difference in mine clearance, counter-terrorism, other security related tasks?
- Can we identify areas of RTD?
- Can we establish a common strategy?

Detection of Explosives for Terrorist-Bombs and Landmine Clearance
Different Applications of Similar Methods

Hiltmar SCHUBERT, PSE GmbH, Germany

1. Introduction

Since the development of modern analysis and detection methods supported by electronic means several different methods are available, which have been improved within the last decades with regard to precision, reliability, quickness and minimum test sample volume. These developments enable us to analyse substances very quickly - in some cases also on-line. The question is, which methods are suitable for application in the field under conditions of mine- and/or terrorist bomb detection. The importance of "Humanitarian Demining" in the last decades aiming at removing millions of landmines in the third world initiated research and development in the industrial countries. National and international programs were started and institutions were founded to solve one of the largest problems of our days. Non-government organisations, the "NGOs" have done an outstanding work in demining. But up to now, the deminers are working with relatively simple devices with very low frequencies and efficiency: Prodding, Dogs and Metal Detection.
The reason for this situation is very simple: all these efforts are financed by humanitarian programmes sponsored by international organisations or governments of industrial countries. This financial help is caused by bad conscience and responsibility felt for the third world and given without any future legal obligation. These unstable circumstances prevent the development of a free and open market, because nobody wants to guarantee the payback of investments producing an expensive demining artificial device.
There will be a quite another situation in the fight against terrorism. The danger addresses all of us, and the authorities are requested to protect people. One of the dangers are assaults of terrorists by the use of explosives. These circumstances produce a demand of detection devices, and, therefore, a market for industry will be formed. The consequence: Sophisticated devices for special applications to detect explosives will be on the market!

2. Sensor Technologies

In Fig. 1 a list of possible detection technologies is shown with a comment of maturity, cost and complexity. These comments may be changed, if we gain other understandings during the workshops of this year. May be, we will also add new technologies to this list.
It is not my intention to go into detail, because this is the theme of our workshop and two or three others this year.
I would like to concentrate my talk on the different conditions, behaviour, design, composition and properties of these explosive charges, because I have been director of a Fraunhofer Institute (ICT) for over 30 years, dealing with all kinds of energetic materials, and being an explosive materials expert in many working groups about demining.

3. Conditions of Detection

3.1 Detection of Landmines

Landmines, usually produced in an explosive factory with professional knowledge, have a relatively small explosive charge of 25 – 250g of TNT. Sometimes also PETN, RDX or other explosives with high performance are used, but more for anti tank mines. The shape of the mines has mostly a rounded design, the charge is in a case made of plastic, steel or sometimes of wood and will be hidden in the ground 5 – 25cm deep. Mines which are connected by trip wires are fixed above the ground. The initiator reacts by pressure or by drawing the trip wire and consists of primary explosive in a metal tube.
The detection will usually be carried out in a rather simple manner by a time consuming prodding.
Most of the demining companies and NGOs are using also trained dogs. Training a dog costs about 2000 Euro, and additional cost of 2000 Euro per year is necessary for livelihood, if a good performance is aspired. In recent years, researchers came to an understanding that the dogs do not smell TNT. It will be more a bouquet of odour of different items. Dinitrotoluol (DNT) is only one example.

If the mines contain metals, a metal detector can be very useful, improved devices are able to detect mines with minimum metal content. If other metal parts are in the ground, more or less false alarms will be the rule.
In a more homogeneous ground, "under ground radar" can be very helpful. The detection of landmines has to be done remotely controlled or with stand-off devices. Very often vegetation has to be removed before the detection can start. This must be done with a cutter also remotely controlled or under protection.
To my knowledge no sophisticated devices for mine detection are used in practice.
During the detection of landmines a distinct area is marked. Therefore only the deminer is acting in such an area. Therefore the danger for other people is limited.

3.2 Detection of Explosives Used by Terrorists

The spectrum of terrorist charges regarding size, shape, confinement, composition and environment is extremely different to landmines.

3.2.1 Size and Shape

The size of a charge may be between less than 1kg up to 1t and more. The different shape of the charge is dependent on the application. Usually the charge has an initiator cap, which is in some cases home made and therefore very dangerous to handle.
Explosive materials which are only transported to another place are more difficult to detect. Plastic explosives can be transported for instance in small quantities and can be transformed later on in a larger charge.
Explosive material may look like any subject you may imagine: Examples are tooth paste, textile rugs and clothing, flower pots, tablets, books, etc.

3.2.2 Confinement

Charges my be used with a soft or strong confinement consisting of metal, plastic, wood, cardboard or any other material in different thickness. The stronger the confinement used is, the more effective will be the detonation effect, also belonging to fragments.

3.2.3 Composition of the Explosives

We must admit, that terrorists have sufficient knowledge about the behaviour of explosives, how to handle the material and how to prepare explosive charges with the different possibilities of composition. Beside literature there is also an access for everybody to the Internet, where you find informations how to prepare explosives and recipes for terrorist usage.("Terrorist Handbook", "Black Book", "Anarchist Handbook", Home-made Detonators", etc.).

There are different sources to get explosive materials:

1. Military Explosives

Under normal circumstances it is relatively difficult to have access to explosives like the relative powerful TNT, RDX, HMX, Nitropenta, Semtex, etc.

2. Commercial Explosives

These are explosives for road-building, for quarries and mining. Mainly Ammoniumnitrate based composition with fuel oil and/or with Nitrocompounds are used. For high performance also Straight Dynamites or Gelatine Dynamites based on Nitrocellulose and liquid organic nitrates with absorbents.
All these commercialized explosives are accessable in most countries only by special licenses. Certainly, in some countries regulations are sometimes handled very careless – as the Oklahoma disaster has shown.
In all Ammoniumnitrate based explosives a strong booster charge of high explosives for the initiation is necessary.
Ammoniumnitrate is also used in large amounts as a component in fertilizers. But additional other components like Ammoniumsulfate cause the non-explosive behaviour of these mixtures.

3. Commercial Substances Suitable for Explosives

These materials for explosives with relatively low performance are in most cases freely available. Examples are Black Powder, Smokeless Powder and many kinds of fire-works. Though these substances do not detonate, in most cases the effects in further distance are still remarkable.

4. Improvised Explosives

All chemical compounds can be used as components for explosives if the oxygen content in the compound is more ore less high enough for a combustion without air.
Mainly molecules with functional groups like:

- NO_2, - $NH\text{-}NO_2$, - $O\text{-}NO_2$ and NO_3+ (Nitro-, Nitramine-, Nitroxy-compounds and Nitrates as salts) and Peroxides are used.

Also mixtures of salts like Nitrates, Chlorates and mainly Perchlorates with organic substances like plastic materials, plastizisers, organic liquids, solvents, etc. can be used.
These combinations are very numerous and will reach quite more than 100 possibilities.
Explosive materials can be prepared in liquid, plastic, slurry and solid state. Very easy to prepare are liquid systems with very high performance. These systems are mixtures of nitric acid, kerosin or nitrobenzene, etc. and were used in World War II from the allied air forces known as "House-Crackers".

5. Primary Explosives

To detonate explosives a detonator primer is necessary. The primer is a capsule made from copper or aluminium with a small pressed charge of a primary explosive like lead azid. The charge will be detonated by an ignition device which react by a relative weak shock or by an electric impulse. Therefore terrorist try to get these initiators by an illegal way. Some terror assaults fail not having suitable detonators. In most cases only professionals prepare primary explosives. For the initiation of low energy explosive charges an additional booster with high energetic material like Nitropenta or RDX is necessary.

6. Powder Trains

Experiences have shown that terrorists also use powder trains to ignite combustible materials in large volumes. In most cases pyrotechnic material is used for this purpose. The event of September 11th has shown, that catastrophic disasters can occur also without powder trains.

3.2.4 Environment

In opposition to landmines which are hidden in the ground in relatively lowly populated areas, for instance in open fields, roads, buildings, ditches or frontgardens, etc. explosive charges of terrorists can be found everywhere, also in highly populated surroundings even to cause an effect as large as possible.
The detonation can be fired by the cap directly, by remote control or with delay.
Because of the different surroundings detection methods may be different between landmines and terrorist bombs.
Spectroscopic means can be used for landmines only by stand off reflection while terrorist objects may be inspected also by transmission.
To prevent terrorist attacks, a main task will be to detect the explosive devices during the underground transport. This can be managed with objects ready to initiate, or the explosive is handled without an initiator only for transport.
Terrorist bombs are relatively easy to detect, because there is a case or box filled with a homogeneous material equiped with an initiating cap fitted with an electric time fuse. Sometimes the explosive charge is screened by a camouflage.
For transport reasons the explosive material may have any shape adapted to the environment. Therefore, such materials are only to be detected by their chemical composition. The relative high density of the material may be a useful indication.

3.3 Explosives Used as Disperser

To distribute nuclear, chemical or biological agents, explosives are used also. If granades or missiles are filled with these materials, an explosive is used with relatively low energy not to destroy the material to be distributed. Otherwise, the agents are distributed by pyrotechnical means.

4. Conclusion

The global political situation will cause an increase of terrorist actions in future. To protect people against this danger, an increase of efforts fighting against terrorism is urgent, and detection of explosives is one of the key problems of antiterrorism.

Because explosive materials can be transported in any shape and design, sensors are necessary which analyse the chemical composition of the material. Alternative measures are dogs or means which are called artificial noses.
We should keep in mind that we will never overcome terrorism, if we fight only against the symptoms. We should think about the reasons why terrorism is coming up.
The truth will be sometimes very inconvenient.

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Chemical and physical properties and the detection of home-made explosives

Michel LEFEBVRE, RMA, Belgium

Detection of *non-regular* explosives

-

Comparison with military explosives

M.H. Lefebvre

Laboratory for Energetic Materials
Department of Chemistry - RMA
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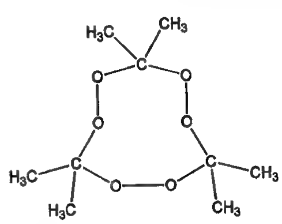
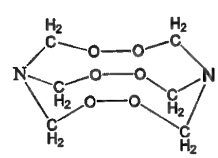
Workshop on Explosive Detection Techniques
Bled Lake, Slovenia / June 02 – 04, 2003

INTRODUCTION



TATP

- White solid
- Primary explosive
- Very sensitive
- Not stable (sublimation)



HMTD

- White solid
- Primary explosive
- Very sensitive

Workshop on Explosive Detection Techniques
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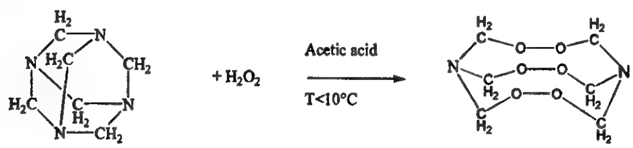
CHEMICAL SYNTHESIS

- **HMTD**



HMTA HMTD

- HMTA: Hexamethylenetetramine, flammable, used in camping 'solid fuel'.
- H_2O_2: Hydrogen peroxide; causes burns, used in pharmacy, easily found in drugstore.
- Acetic acid is used pure, is corrosive and can cause burns. It can be found in drugstore or supermarket (diluted).
- Synthesis: easy to perform, temperature needs to be controlled.

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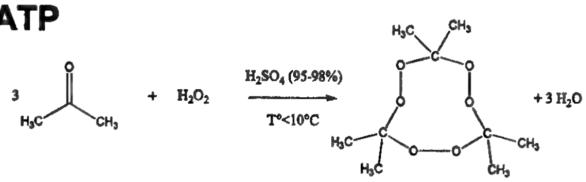
CHEMICAL SYNTHESIS

- **TATP**



Acetone TATP

- Acetone: very flammable and slightly toxic, easy to find in supermarket or drugstore.
- H_2O_2: Hydrogen peroxide; causes burns, used in pharmacy, easily found in drugstore.
- Sulphuric acid is a very strong acid, is very corrosive and causes burns.
- Synthesis is not quite easy, the temperature must be very well controlled in order to obtain a high purity product.

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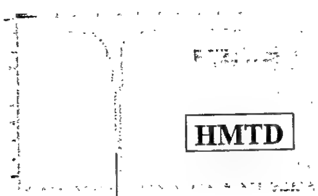
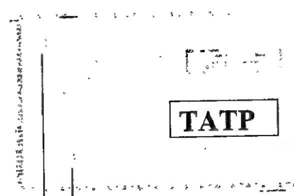
CHEMICAL CHARACTERIZATION

- **DSC** (1mg/ scan from 50°C to 400 °C)





Exothermic peak at 165 °C

Exothermic peak at 120 °C

Endothermic peak at 80°C

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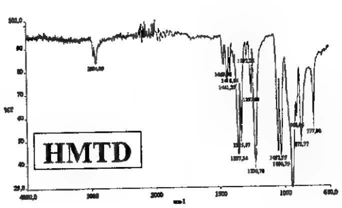
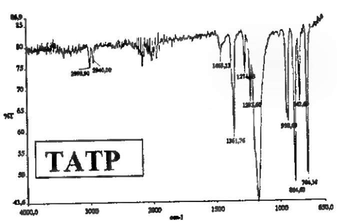
CHEMICAL CHARACTERIZATION

- **FTIR** (scan from 650 cm^{-1} to 4000 cm^{-1})





Combined with DSC, the FTIR enables us to perform reliable analysis.

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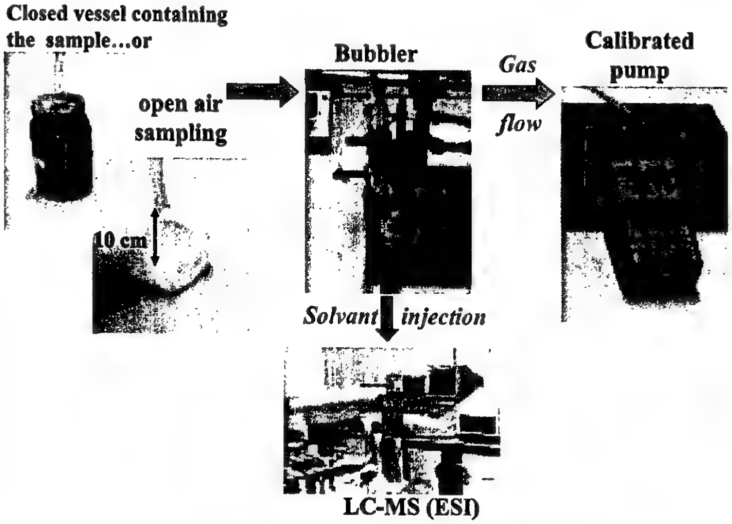
Sampling / Detection Chain



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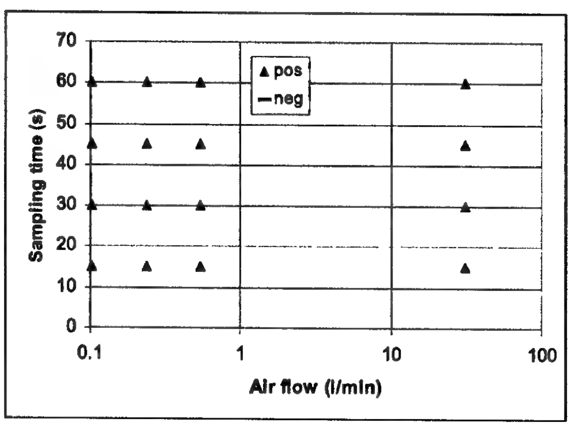
Detection of TATP

Open air sampling



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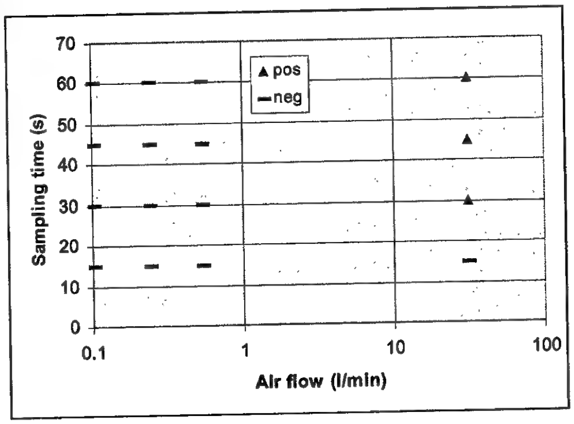
Detection of HMTD

Open air sampling



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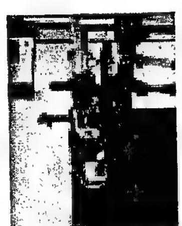
Sampling / Detection Chain

Closed vessel with sample

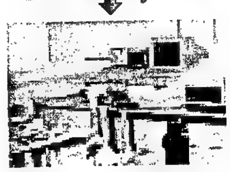
Bubbler



Gas flow

Calibrated pump

Solvant injection



GC-MS

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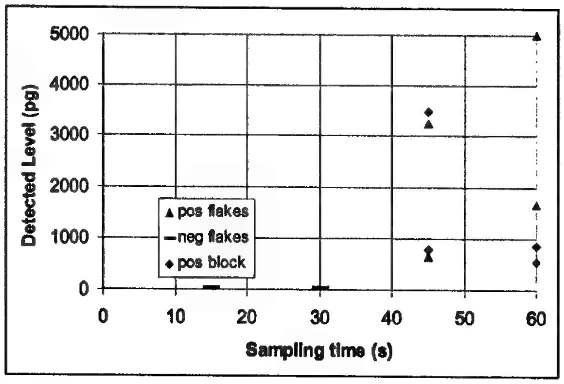
Detection of TNT

Closed vessel with sample



Rem: heated to 40°C
air flow 31 l/min

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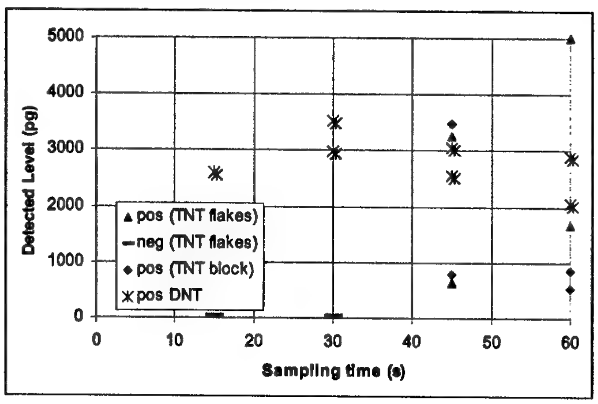
Detection of DNT

Comparison TNT - DNT

Closed vessel with sample



Rem: heated to 40°C

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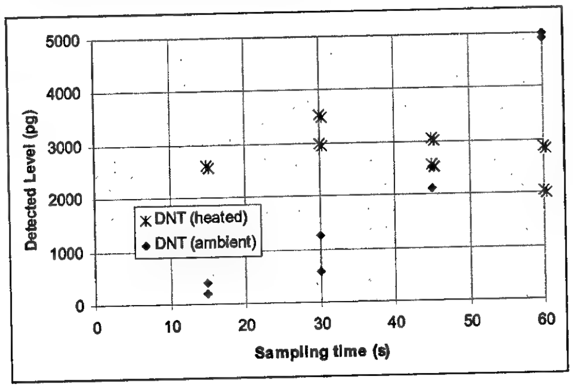
Detection of DNT

Heated and not-heated

Closed vessel with sample



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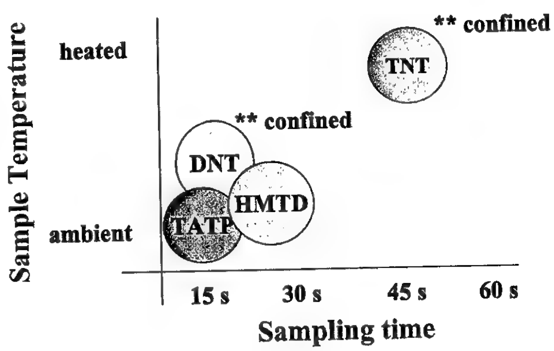
Comparison TATP – HMTD – DNT - TNT

- TNT is quite difficult to sample
- DNT has properties comparable to HMTD and TATP…



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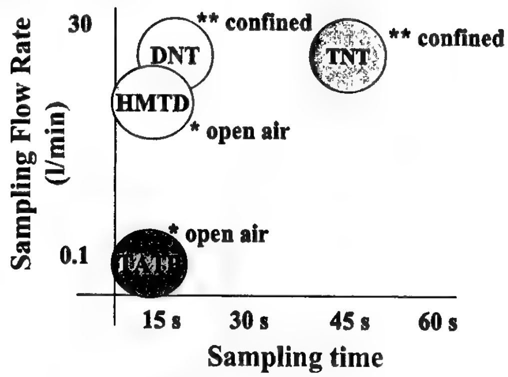
Comparison TATP – HMTD – DNT - TNT

- TATP can be easily detected
- Both TNT and DNT require high sampling flow (similar to HMTD)



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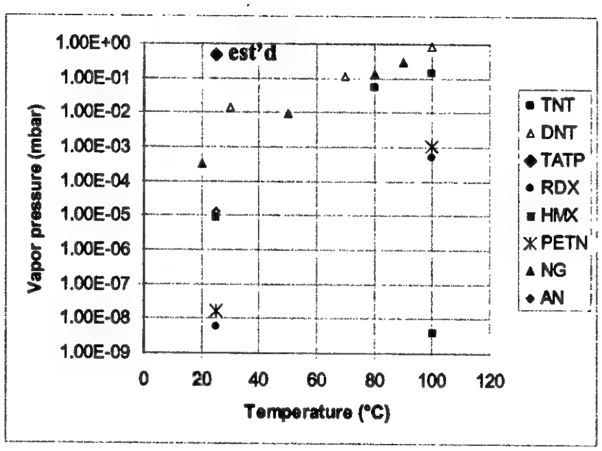
Vapor Pressure

of various high explosives



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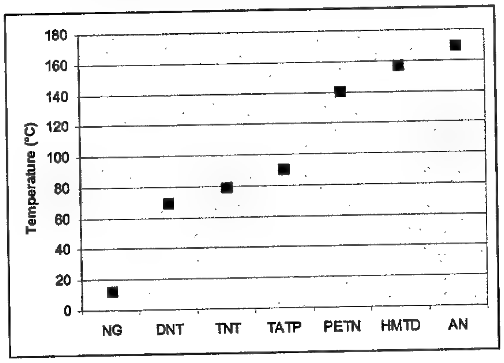
Melting Temperature
of various high explosives



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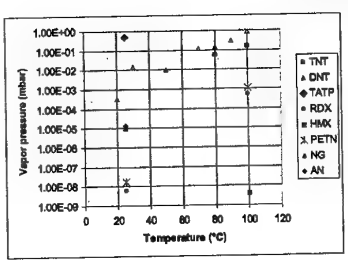
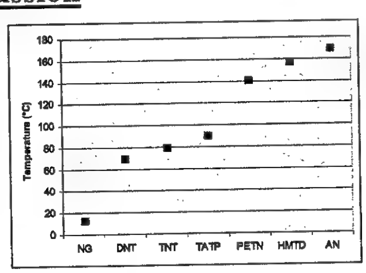
Discussion





- Near melting temperature ≠ near vapor pressure @ ambient temperature
- In the (L)-phase domain, vapor pressure are of the same order of magnitude
- Large influence of temperature on 'detectability' in the range 20°C – 40°C (see experiments)

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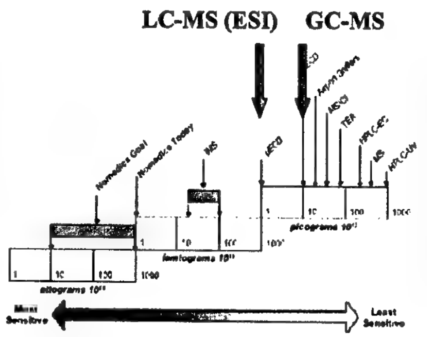
Detection Limits
of various technologies



Detection Method	Limits
High Performance Liquid Chromatography-Ultraviolet (HPLC-UV)	1 nanogram (ng)
Mass Spec	800 picogram (pg)
High Performance Liquid Chromatography-Electrochemical (HPLC-EC)	600 pg
Thermal Energy Analysis	30-50 pg
Mass Spec-Chemical Ionization (MS-CI)	20 pg
Airport Sniffers	20 pg
Electron Capture Detector (ECD)	10 pg
Micro Electron Capture Detector (µECD)	1 pg
Ion Mobility Spectrometer (IMS)	50-100 femtogram (fg)
Nomadics Amplifying Fluorescent Polymer (AFP)	*1 fg*

Conclusion

- **Importance of physical properties:**
  - **Sample temperature**
  - **Sample vapor pressure**
- **Importance of operating parameters:**
  - **Sampling time**
  - **Sampling flow rate**
  - **Confinements**
  - **Analysis time**
- **Importance of (chemical) detection technology:**
  - **NOx-groups ease the detection**
  - **Many improved technologies are emerging**
  - **Problem of cross-contamination**

Overview of technology development in explosive detection

Louis WASSERZUG, TSWG, Special Operations Washington, USA

TECHNICAL SUPPORT WORKING GROUP

Explosive Detection Brief
June 2, 2003

Subgroup Mission

- Identify, prioritize and execute research and development projects
- Satisfy DoD, interagency, state and local user requirements
- Focus existing and emerging technology in the area of explosives detection and diagnostics.
- Long term sustained approach.

Explosive Detection Focus Areas

- **Standoff Detection**
  - **remote detection, large vehicle bombs**
- **Suicide Bomber Detection**
- Short Range Detection & Diagnostics
- Marking Agents
- Canines
- Cargo Screening

Technical Approaches

- Nuclear
  - Neutrons
  - X-rays
- Optical
  - Infrared (Heat Lamp or Laser)
  - Ultraviolet (Laser)
- Electromagnetic (Other)
  - Millimeter/Terahertz
  - Nuclear Quadrupole Resonance
- Biosensors

Standoff Detection

Focus: Technologies for detection of large vehicle bombs.

Completed Tasks
- Residue Detection by Differential IR Absorption
- Laser Based Detection of Explosives
- TNT Detection by Laser Induced Fluorescence

Current Task
- Associated Particle Explosive Imaging System

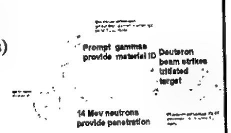
TNT Detection by Laser Induced Fluorescence

Technology:
- Laser induced photo dissociation
- Laser Induced fluorescence of fragments

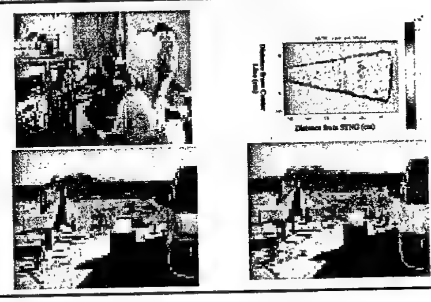
Issues:
- Environment can impede performance
- Laser can cause physical damage

Associated Particle Imaging (API)

- Technology
  - Fast neutrons in, gamma rays out
- Status:
  - Demonstrated C-4 (100 lbs) detection at 10 feet
- Issues:
  - Significant background noise
  - Interrogation times long (hours)
  - Significant engineering issues
- Prognosis:
  - High risk
  - Possible remote application



Associated Particle Imaging (API)



Suicide Bomber Detection

Focus: Technologies to detect human carried explosive devices

Current Tasks
- Man Portable Passive Millimeter Wave
- Non-Imaging Millimeter Wave
- Terahertz Spectroscopy/Imaging

Way Forward

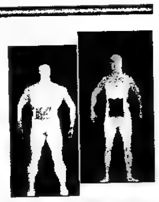
- Adapt concept of operations to implement practical alternatives
- Look at imaging systems as an alternative to detection
- Look at remote detection as an alternative
  - DHS BAA closes June 13
- Consider partial solutions

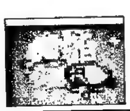
Interim Solutions

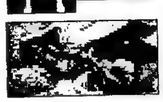
Requirement: Suicide bomber detection in entry-point and standoff applications

- Evaluate commercial technologies
- Move entry-point away from assets

Approach: Low Dose X-ray







Short Range Detection and Diagnostics

- NQR/CT False Alarm Reduction
- NQR Personnel Screening
- Walk-Through Portals for Personnel Screening
- Next Generation Handheld Detectors
- Explosives Detection for Passengers and Baggage

Marking Agents

Focus: Develop technologies that enables the marking of plastic explosives that will make them easier to detect. This includes fostering the means to make marking agents available and affordable to all manufacturers of plastic based explosives.

- Low Cost Production of DMNB
- Low Cost Detectors for Taggants

Canines

Scope: Develop better understanding of canine detection ability and canine/human interaction. Improve effectiveness and consistency of canine/handler team.

- Canine Training Aids
- Generalization and Contamination
- Canine Selection and Rearing
- Handler Selection and Training
- Canine Stress

Detection of plastic explosives in explosive devices

Petr MOSTAK, Research Institute of Industrial Chemistry, Czech Republic

Abstract
Plastic explosives have been often used as explosive charge in military products and also misused in improvised explosive devices for terrorist attacks.
The application of vapour and trace detection by electronic detectors for detection of plastic explosives is evaluated, the effectiveness of detection by colour chemical reactions is discussed. The marking of plastic explosives for detection can substantially increase the ability of the vapour detection.
The detection of plastic explosives by dogs is a very effective method, it is possible that the dogs are looking for, similarly as in the detection of mines, not only vapours of the main component as RDX or PETN but also the "smell" of the plastic explosive.
Bulk detection technologies, which can bring the image of content of suspicious object are important tools to identify a presence of the improvised explosive device. The promise for near future are the methods which are giving the confirmation of explosive presence by determination of the density typical for plastic explosive and analyse the chemical composition by x-ray angular diffraction or other radiation analysis.
Simultaneous use of the vapour and trace detection performed by electronic detectors and/or dogs and bulk detection can give the substantial synergy in detection of hidden explosive charge including improvised explosive devices used in terrorist attacks.

1. Introduction

Plastic explosives have been used in many criminal acts, in which improvised explosive devices was a tool of criminal or terrorist bomb attacks. Well known are the attacks on civil aeroplanes at which the big number of passengers was killed and these criminal events shocked the world public opinion.
The danger of plastic explosives is usually connected with the high explosive strength, easy forming of this product and poor detection of plastic explosives.
The destructive and further properties of plastic explosives have been strongly exaggerated in information spread by mass media and an unrealistic image of this product was implemented to public and to some part of scientific community.
This contribution deals with the methods, which are used for detection of plastic explosives, considering the feasibility and effectiveness of detection and also conditions, which can influence the performance of detection procedures.

2. Composition of plastic explosives

The plastic explosives are composed from two main parts, crystalline high explosive and plastic binder. The usual explosive components of plastic explosives are RDX or PETN, in some plastic explosives both these components are used. The content of high explosive is usually in the range 80-95 %
The plastic binder is composed from a polymeric substance and suitable plasticizer. Polyisobutylene, polystyrene, polyacronitrile, or polyeethylene are often used as polymers. The usual plasticizers are dioctylphtalate, dibutylphtalate or dioctylsebacate.

3. Detection methods

The detection procedures used in detection of plastic explosives are in principle similar to methods used for detection of other explosives. The detection is based on the identification of RDX or/and PETN, which are the main components of these explosives.
The trace analysis detection is based on the following possibilities:

- vapour detection
- particles detection
- combination of vapour and particles detection
- detection by colour reactions
- detection by dogs or other animals

Further important group of detection methods is bulk detection, which is using such systems as enhanced X-ray, neutron radiation, NQR, computing tomography or MM wave imaging.

4. Detection of vapours

Detection of plastic explosives by vapours is uneasy taking into account the very low vapour pressure of RDX and PETN. The substantial difference in the vapour pressure among RDX and PETN and other explosives can be seen from the Table 1.

Table1 Vapour pressure of some explosives and by-products at 25°C

Compound	Vapour pressure (ng/l)
RDX	0.04
PETN	0.09
HMX	0.38
TNT	70
NG	4000
2,4 DNT	1440
1,3 DNB	8140

The low vapour pressure of RDX and PETN was the reason, that in former times, when vapour detection by electronic detectors was the main detection method, the view was appeared, that the detection of hidden plastic explosive is not feasible.

It can be also understood, from the values of vapour pressure of TNT and some by-products why the mines containing TNT can be detected rather by identification of vapours of DNT than vapours of TNT.

The further reason, why detection of plastic explosives by vapour detection is in some conditions complicated is the influence of temperature on the vapour pressure of explosives.

The vapour pressure of any chemical compound is dependent on the temperature by the logarithmic equation: $\log P = A - B/T$

The dependence of the vapour pressure on temperature at some explosives was experimentally estimated and published [1].

The relevant equations are presented in the Table 2. The graphic demonstration of this dependence at RDX and PETN is shown in the Figure 1 and 2.

Table 2 Dependence of vapour pressure of some explosives on temperature

Compound	Equation
RDX	$\log P\ (ppt) = -6473/T(K) + 22.50$
PETN	$\log P\ (ppt) = -7243/T(K) + 25.56$
TNT	$\log P\ (ppb) = -5481/T(K) + 19.37$
NG	$\log P\ (ppb) = -4602/T(K) + 18.21$
AN	$\log P\ (ppb) = -3541/T(K) + 12.97$

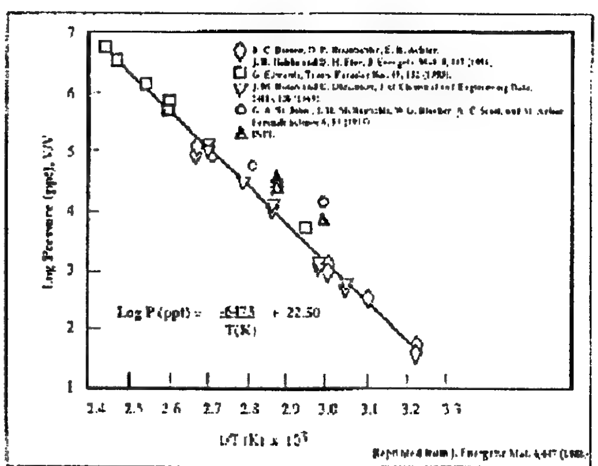


Figure 1 Change of vapour pressure of RDX with temperature

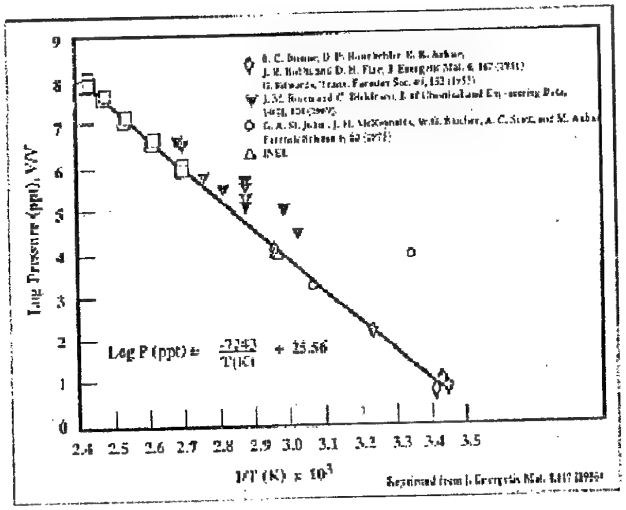


Figure 2 Change of vapour pressure of PETN with temperature

The dependence of vapour pressure on temperature is unfortunately most profound at RDX and PETN, compounds, that have the low vapour pressure even at higher temperatures.
The dramatic change of the vapour pressure of some energetic materials at decreased temperatures can be the basic reason, why the detection of plastic explosives but also the detection of other explosives containing RDX and PETN using electronic detectors is not easy. The good preconcentrator having the preconcentration factor 100 at minimum can improve the feasibility of vapour detection of plastic explosives at temperatures lower than 10°C.
The change of vapour pressures of some explosives in the temperature range 0-30°C is demonstrated in the Table 3. [2]

Table 3 Vapour pressure in temperature range 0 – 30 °C

Vapour pressure	0°C	10°C	20°C	25°C	30°C
RDX (ppt)	0.06	0.43	2.57	6.03	14.45
PETN (ppt)	0.11	0.93	6.92	18.20	45.71
TNT (ppb)	0.19	1.00	4.57	9.55	19.05
NG (ppb)	22.39	89.12	316.2	588.8	1047.1
AN (ppb)	1.00	2.88	7.35	12.30	19.05

They are also further factors influencing the presence of explosive vapours near the object in which the improvised explosive device is hidden. The diffusion and effusion of vapours from the surface of explosive charge through the various barrier materials, including packing, results in the emission flow of vapour. The adsorption of vapours on various surfaces and the dissipation of vapours into surroundings of the object in which the explosive charge is hidden are decreasing the quantity of vapours which could be collected by sampling parts of electronic detectors.
Taking into account cases, when plastic explosives were used in improvised explosive devices for bomb attacks on civil planes, and the uneasy detection of plastic explosives, the UNO decided to establish the marking of plastic explosive for detection. The objective of this initiative was the significant increase the feasibility of the vapour detection of plastic explosives used as explosive charge in bombing devices.
The Convention on the Marking of Plastic Explosives for the Purpose of Detection was prepared by ICAO and agreed during the International Conference in Montreal in March 1991.
The detection agents and their minimum concentration in the finished plastic explosives at the time of manufacture have been specified in the Technical Annex to the Convention [3].

Some changes in the Technical Annex was later accepted on the base of practical experience achieved in marking of plastic explosives.
The actual specification of detection agents is shown in the Table 4.

Table 4 Detection agents and minimum concentration

Name of detection agent	Molecular formula	Minimum concentration
Ethyleneglycoldinitrate (EGDN)	$C_2 H_4(NO_3)_2$	0.2 % by mass
2,3-Dimethyl-2,3-dinitrobutane (DMNB)	$C_6 H_{12} NO_2)_2$	0.1 % by mass
para-Mononitrotoluene (p-MNT)	$C_7 H_7 NO_2$	0.5 % by mass

The further change is in preparatory phase. The theme for discussion is the raising of minimum concentration of DMNB to 1%. This measure should ensure the sufficient DMNB concentration and a suitable emission flow of this marking agent during the whole shelf-life of plastic explosive. Some producers increased already voluntarily the DMNB content to 1% to achieve this goal.
The main effect of marking agent on detection is its high vapour pressure, which enables to gain the sufficient mass of vapour by electronic detectors.
The vapour pressures of some explosives and marking agents are presented in the Table 5.
It was found, that the vapour pressure of DMNB emitted from the marked plastic explosive is approx. 50% of the vapour pressure of pure DMNB. It means, that the vapour pressure of this marking agent is by 5 orders higher than the vapour pressure of PETN or RDX. Thus the marking of plastic explosives by DMNB gives to this product the easy detection similar to NG containing explosives.

Table 5 Vapour pressures of explosives and marking agents at 25°C

Compound	Vapour pressure (ng/ml)
o-MNT	860
EGDN	320
p-MNT	170
DMNB	12
NG	4
TNT	0.07
RDX	0.04×10^{-3}
PETN	0.09×10^{-3}

In the Czech Republic, all plastic explosives produced, including Semtex plastic explosives, are marked for detection according to the conditions of Montreal Convention from May 1991. The intention to mark additionally the old stocks of plastic explosives is considered.

5. Trace detection

5.1. Detection of fingerprints

The trace or particle detection of plastic explosives is oriented on the 2 basic types of traces: fingerprints and particles of explosives. These particles are dissipated on the surfaces near to the place, where the explosive preparation, forming or other manipulation was done.
The quantification of fingerprints prepared from plastic explosives on various surfaces was studied by many authors, and interesting results were obtained [4,5,6,]. It was found, that hands contaminated by plastic explosives are producing massive fingerprints, one fingerprint contains according to the conditions 500-3000 ng of RDX or PETN. The mass of fingerprints prepared from Semtex H by the bare thumb and thumb in glove, and the mass of explosive, which was collected from the fingerprint by swabbing, is presented in the Table 6.
The data presented in the Table 6 are proving, that we can collect by swabbing 50-70 % of the fingerprint mass. It can bee seen, that the use of gloves has not substantial effect on the mass of explosive contained in fingerprints.
Taking into account the sensitivity of up-to-date electronic detectors, which is in the range of 20-200 pg, it is very clear that we are able to collect by swabbing of only 1 fingerprint much more explosive, than we need to positive detection.

Table 6 RDX content in fingerprints prepared by Semtex H on polyethylene

Sample	Fingerprint mass	Swab	Mass of rest
Blank 1	0	0	0
Glove	3 135 ng	2 334 ng	978 ng
Blank 2	0	0	0
Bare thumb	2 303 ng	1 124 ng	1 155 ng

The secondary contamination can arise by touch or other type of contact with fingerprints of plastic explosives. Also from these secondary traces the sufficient mass of explosive for positive detection can be gained by standard collection methods (swabs or vacuum sampler).

5.2. Detection of further types of contamination.
There are further principles of contamination by plastic explosives. It was found, that in the process of moulding, forming and manipulation, the substantial number of particles of plastic explosives is dispersed in the air. These particles, transported by the movement of air, cause the contamination of surfaces in surroundings including persons, working tables, walls and various objects. Taking into account, that the average particle size of crystalline explosive present in plastic explosive is approx. 30 microns having the mass 40 ng, we can assume, that the collection of 1 such particle is sufficient for successful detection.
The experience from model and field-testing confirms, that the contamination of surfaces, persons and objects at working and manipulation with plastic explosives is high. The detection of this contamination can be effectively used as the signal that a further detail search is necessary. This signal cannot be considered as a relevant information, that some hidden explosive charge or person preparing some bomb attack was found. Unfortunately, they are many other situations from which, the contamination by particles can arise.

6. Simultaneous vapour and particles detection

The low vapour pressure of explosive components of plastic explosives is the reason, why detection of plastic explosives by vapours is rather uneasy. The marking of plastic explosives for detection is substantially improving the vapour detection, but there is still some quantity of old stocks of unmarked plastic explosives in many countries. There are also problems with detection of marking agents by some detectors.
Therefore, detectors, which are able to detect both vapours and particles will be more effective in the detection of hidden explosive devices.
In fact, the detection of vapours gives us not quite the same information as detection or explosive particles. The detection of traces gives us the information about the contamination of persons or objects by explosives but not the prove or strong suspicion, that explosive charge is present. On the other hand, the vapour detection enables the assumption that some explosive charge was probably found.
The differentiation between these 2 possibilities is at most detectors complicated because in both cases the collected samples enter the analytic part of detector after thermal desorption in the form of vapours .
Anyway, the simultaneous vapour and particles detection gives us the synergetic effect, because in various scenarios, each of both methods has a different effectiveness and the combination will increase the probability of positive detection.

7. Detection by colour reactions

The detection of plastic explosives by colour reactions is a version of trace detection. The particles collected by swabs or vacuum collectors on filter paper are reacting with testing solutions and specific colours are obtained in reactions of explosives with reactants. In application of the detection set DETEX II, which was developed in our research institute, the pink colour is evolved at the detection of plastic explosives containing RDX and/or PETN.
The sensitivity of colour reaction is lower, than the sensitivity of electronic detectors. The advantage of this method is low costs and easy operation. The fact, that we have no losses of explosive during the analytical procedure, results in quite good effectiveness of this method.
The developing of characteristic pink colour at plastic explosive takes more time than in case of pure RDX or PETN. The reason is the time necessary for diffusion of reaction solutions through the layer of binder to the surface of crystalline RDX or PETN.

8. Detection of plastic explosives by dogs

It is well known, that dogs are the effective tools in detection of hidden explosive charges. Therefore, the use of dogs in detection of improvised explosive devices, mines and other types of ammunition is used in many countries.

Substantial effort has been expended to understand the mechanism of dog sensing and estimate the sensitivity of the dog's olfaction system. Some aspects of dog work are clear, some need the further work.

Dogs are able to detect the hidden charges of plastic explosives with high effectiveness. In fact, the dogs are able to detect hidden charges also at decreased temperature, when electronic detectors are not able to detect plastic explosives do to very low vapour pressure of RDX and PETN.

Some field tests performed last year in collaboration with Czech police confirmed this conclusion and some further knowledge was gained [7].

The general ability of tested dogs to detect explosives is seen from the results presented the Table 7

Table 7 Detection of hidden explosives by dogs

Compound	Name of dog (dog's No)				
	Dany (1)	Adeline (2)	Bordaux (3)	Fox (4)	Tom (5)
HMX	+	+	+	+	+
RDX	-	(+) (+) +	(+) +		
Permonex				+	+
TNT	+	+			
SEMTEX H			+	+	
SEMTEX 1A	+				+
SEMTEX 1A + DMNB		+	+		
PETN				+	+
NG SP	+	-			
Perunit			+	- +	
DMNB			+	-	

Note: + detection (+) mistaken detection
- miss

The dogs No 1,4,5 were German shepherds trained in the Czech Republic, dogs No 2 and 3 were Labradors trained in the USA.

The dogs were looking for 50g of explosive inserted in PE bag which was closed by weld. The explosive charge was inserted in the paper box 30 min before testing. In the test 4 blank boxes and 1 box with explosive were examined at each explosive.

The results obtained confirmed, that dogs can detect plastic explosives without any problem.

The ability of dogs to detect the fingerprints including fingerprints of the plastic explosive SEMTEX 1A was studied in further tests. It was proved, that the dogs can effectively detect the presence of plastic explosive in fingerprints and also the contamination of surfaces by dispersed particles, evolved at moulding and forming of plastic explosives.

It is not very clear, if detection of plastic explosives from fingerprints and particles on surfaces is achieved only by collecting of vapours from natural vapour pressure, which is very low. The dog can possibly collect more vapour in the process of sniffing by emitting the stream of warm and wet air in quick short intervals and sucking in back the air enriched by evolved explosive vapours increasing thus the detection effect.

The model test was also performed in which inert aerosil (very fine SiO_2) was saturated by vapours of several explosives. After 14 days of saturation 50g sample was inserted in PE bag and closed by weld. Dogs in various scenarios positively identified the samples.

This result could bring some contribution to the discussion, that inert dust particle are able to adsorb on its surface some quantity of explosive vapours and act as micropreconcentrator. The warm and wet air used by dog at sniffing could evolve the explosive vapour from the particle surface.

9. Bulk detection

The radiation technologies are considered to be the main component of the bulk detection. These methods enable to produce the image of the hidden object shape and many of methods can characterise the inner content of the object.

Very often x-ray systems are used, the enhanced version as scan x-ray and computing tomography are increasing the identification possibility for improvised explosive devices.

The type of explosive is not very important for successful detection, the substantial role is playing the design of explosive device including type of starting mechanism, sort of detonator and configuration of the device.

Some small advantage for bomb maker is the plasticity of plastic explosives, which enables the easy forming of explosive charge to required shape.

The systems, which are able to identify the chemical structure of components such as TNA, FNA, NQR or angular X-ray diffraction, have the same effectiveness for plastic explosives as for such explosives as HMX, RDX, and PETN. The reason is that plastic explosives contain usually 80-95 % of RDX or PETN, and the small quantity of plastic binder does not influence the result of the radiation analysis in important manner.

10. Conclusions

The detection of plastic explosives used in improvised explosive devices, which are usually hidden in various objects, is not very different from the detection techniques used at other explosives. .

The low vapour pressure of plastic explosives, which decrease the feasibility of vapour detection of plastic explosives especially at lower temperatures, is not specific property only of plastic explosives but also many other explosives based on HMX, RDX or PETN have the similar problem. Therefore, the view, that plastic explosives in contradiction with other explosives are not detectable, is not proper and has not any technical background

The problem of low vapour pressure can be solved by marking of plastic explosives for detection, or/and by the use of effective preconcentrators having the concentration factor at least 100.

The dogs are very efficient tools for detection of hidden charges of plastic explosives, they can detect plastic explosives also at lower temperature. At this condition are dogs much better than electronic detectors. We can suppose, that the sensitivity of dog is higher in comparison with electronic detectors by approx. 3 orders.

The plasticity of plastic explosives enables to form this product in various shapes including sheets. Some shapes, as sheets for instance, can complicate the bulk detection in the phase of evaluation of the image obtained and also at radiation analysis of the content of suspicious object.

11. References

[1] B.C. Dionne, D.P.Rounbehler, E.K.Achter, J.R.Hobbs, D.H.Fine, Vapour Pressure of Explosives, Journal of Energetic Materials, 4, 447-472 (1986)

[2] P. Mostak, Vapour and Trace Detection, Proceedings of the NATO ARW on Vapour and Trace Detection of Explosives for Anti-Terrorism Purposes, March 19-20,2003 Moscow, Russia

[3] Convention on the Marking of Plastic Explosives for the Purpose of Detection, ICAO Montreal 1991

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[5] L.Elias, Swab Sampling of PETN and RDX Deposits on Various Surfaces, 4th Workshop on the detection of explosives, Ascot, Berkshire, UK

[6] P.Mostak, M.Stancl, Detection of Semtex Plastic Explosives, Proceedings of the NATO ARW on Detection of Explosives and Landmines, September 9-14 2001 Saint Petersburg, Russia

[7] M. Stancl, Detection of Traces of Explosives by Means of Sniffing Dogs, Proceedings of the NATO ARW on Vapour and Trace Detection for Anti-terrorist Purposes, March 19-20, 2003, Moscow, Russia

Detection and Imaging with NQR, THz, and X-ray techniques

Garth SHILSTONE, DSTL Fort Halstead, UK

Notes

Detection and Imaging with NQR, THz, and X-ray Techniques

Dr. Garth Shilstone
Dr. Ian Jupp

ITF Workshop, Bled, Slovenia, 2-4 June 2003

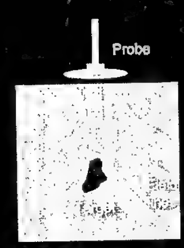
Nuclear Quadrupole Resonance (NQR)

NQR - Basic Physics

- ^{14}N: I=1; 0 (400kHz) - 6MHz (λ>50m)
- Detection only (imaging possible, but time consuming)
- Penetration - relatively good through non-metals
  - 20-30cm through most materials (wet or dry)
- Water has little effect
- Highly discriminating
  - frequency depends on crystal structure
- Health issues
  - radiowaves - low risk

NQR - Detection

- Excite sample with a series of radio frequency (rf) pulses from a tuned probe
- Detect response of sample
  - unique to a particular material
- Probe design
  - Simple coil
  - Cheap components
  - Uses rf engineering techniques



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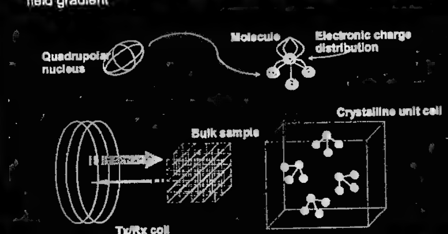
NQR - Interaction

- Interaction of nuclear quadrupole moment with surrounding electric field gradient



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NQR - Signal processing

- Simple thresholding
  - FT (time domain data to frequency spectrum)
  - threshold signals above noise
- Complex processing
  - Correlation of frequency, phase, relaxation decay constants
  - Correlation of more than one resonance line
  - Matched filter (time domain or frequency spectrum)
  - Maximum entropy or linear prediction methods

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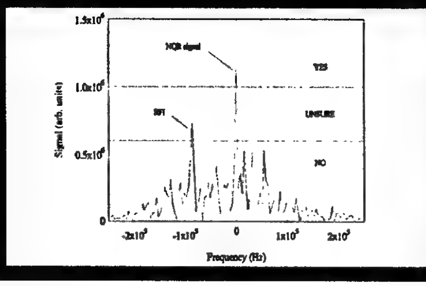
Notes

NQR - Signal processing (threshold)



NQR - Current Capability

- Landmine detection
  - RDX fills
    - all AP and AT non-metal mine types
  - TNT fills
    - non-metal AT mines
    - non-metal AP mines still difficult (detection time ~minutes)
- Other explosives
  - PETN, AN, Tetryl, HMX (all N or Cl containing explosives)
- Other applications
  - luggage screening, people screening, vehicle screening

NQR - Scenarios

- Mine detection
  - AP mines (10-15cm depth)
  - AT mines (25-30cm depth)
- People screening
  - Hand-held (wand)
  - Portal
- General search
  - Luggage (aviation/transport security)
  - Vehicle (port of entry, building protection)

NQR - Maturity

- Quantum Magnetics (US)
  - prototype equipment (hold baggage screening)
  - lab/prototype equipment (mine detection & people screening)
- QR Sciences (Australia)
  - prototype equipment (hold baggage screening)
- Other organisations
  - R&D only
    - NRL, King's College London, Dstl, etc.

NQR - Detection Summary

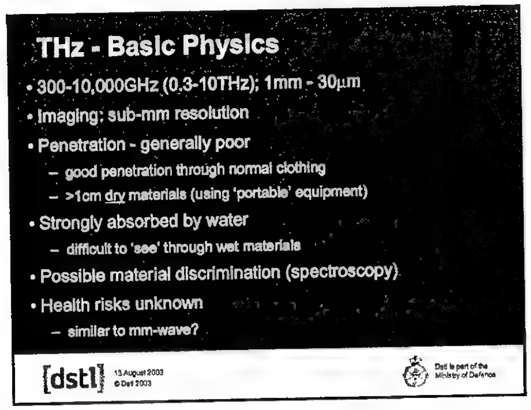
- Detects threat (explosive) directly
  - clutter & background materials not a problem
- Penetrates all barriers except metal
  - up to about 30cm readily achievable
- Most explosives detectable
- Only prototypes available right now
- High power consumption

NQR - Pros and Cons

- Pros
  - Penetrates all non-metal materials, including wet soil
  - Metal detection
  - Detects almost all explosives
  - User friendly (red/green light)
  - High PoD, low FP/FN
  - Works at useful distances
  - Works on uneven surfaces
  - Works in presence of metal (cans, wires, nails, etc)
- Cons
  - Will not penetrate metal
  - Will only detect explosives for which it has been 'tuned' - requires intelligence as to target material
  - Relatively high power consumption

Notes


[dstl]
TeraHertz (THz)


THz - Basic Physics
• 300-10,000GHz (0.3-10THz); 1mm - 30μm
• Imaging: sub-mm resolution
• Penetration - generally poor
– good penetration through normal clothing
– >1cm dry materials (using 'portable' equipment)
• Strongly absorbed by water
– difficult to 'see' through wet materials
• Possible material discrimination (spectroscopy)
• Health risks unknown
– similar to mm-wave?
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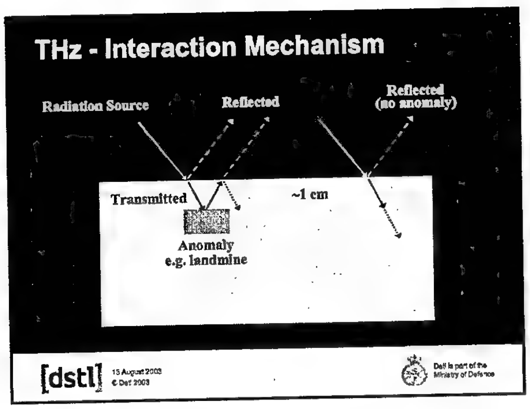
THz - Interaction Mechanism
Radiation Source
Reflected
Reflected (no anomaly)
Transmitted
~1 cm
Anomaly e.g. landmine
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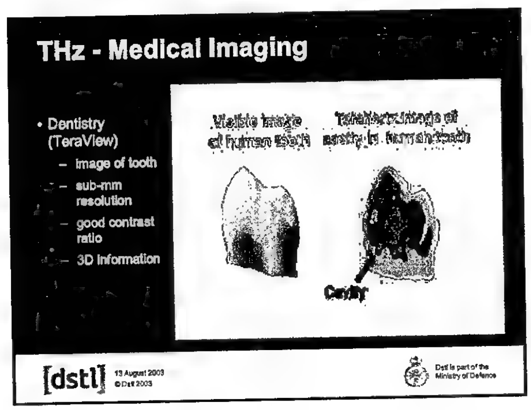
THz - Medical Imaging
• Dentistry (TeraView)
– image of tooth
– sub-mm resolution
– good contrast ratio
– 3D information
Cavity
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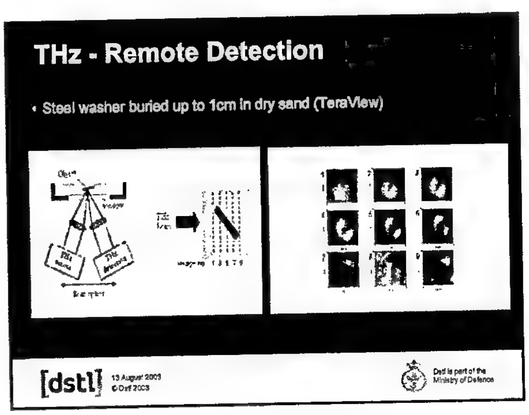
THz - Remote Detection
• Steel washer buried up to 1cm in dry sand (TeraView)
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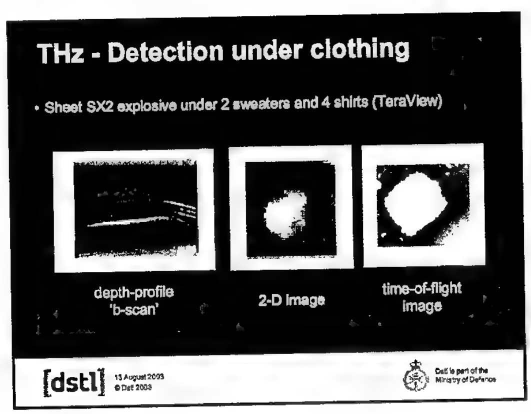
THz - Detection under clothing
• Sheet SX2 explosive under 2 sweaters and 4 shirts (TeraView)
depth-profile 'b-scan'
2-D image
time-of-flight image
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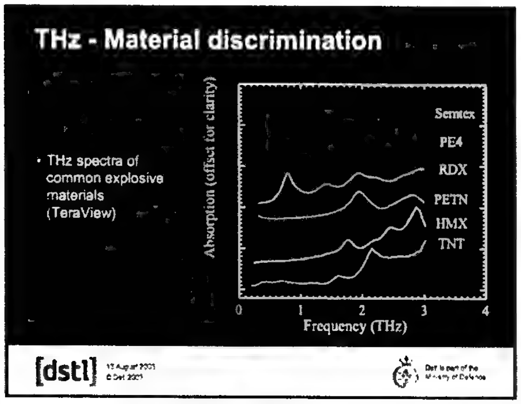
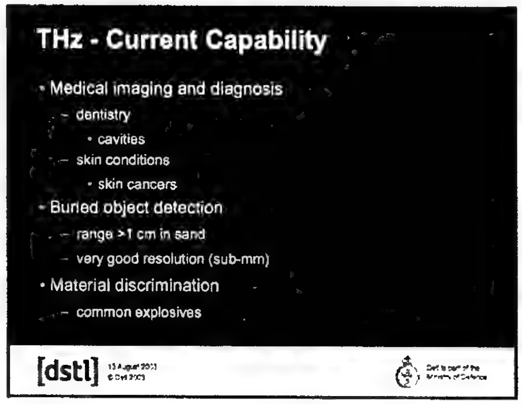
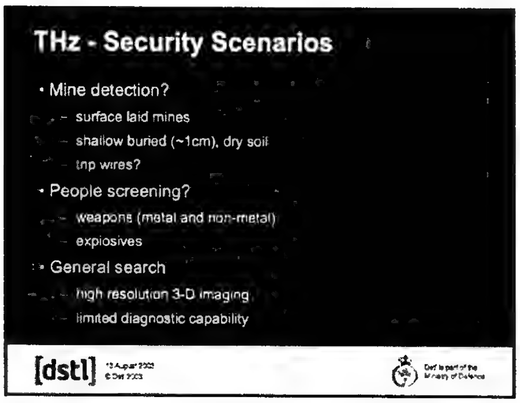
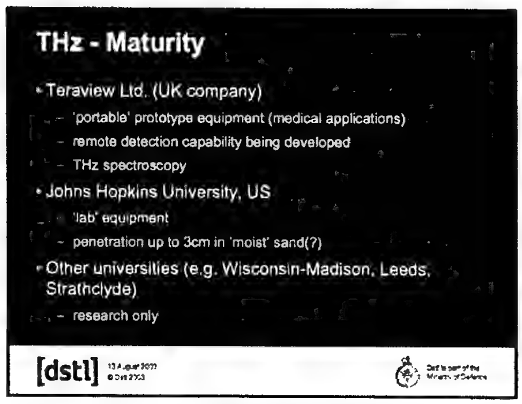
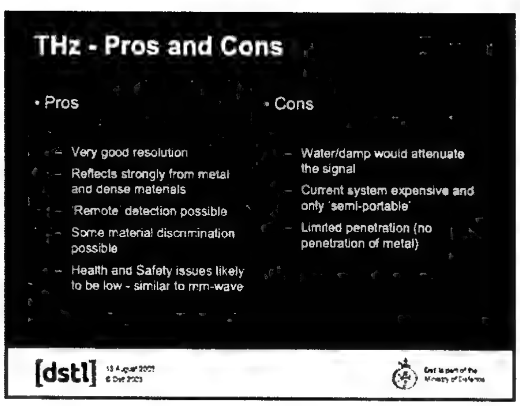
Notes

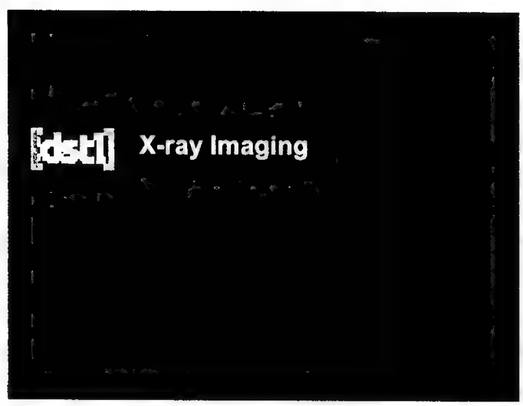

THz - Material discrimination
• THz spectra of common explosive materials (TeraView)
Absorption (offset for clarity)
Semtex
PE4
RDX
PETN
HMX
TNT
0
1
2
3
4
Frequency (THz)
[dstl]


THz - Current Capability
• Medical imaging and diagnosis
– dentistry
• cavities
– skin conditions
• skin cancers
• Buried object detection
– range >1 cm in sand
– very good resolution (sub-mm)
• Material discrimination
– common explosives
[dstl]

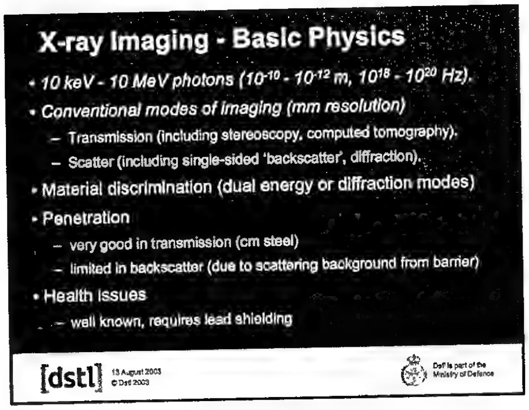

THz - Security Scenarios
• Mine detection?
– surface laid mines
– shallow buried (~1cm), dry soil
– trip wires?
• People screening?
– weapons (metal and non-metal)
– explosives
• General search
– high resolution 3-D imaging
– limited diagnostic capability
[dstl]


THz - Maturity
• Teraview Ltd. (UK company)
– 'portable' prototype equipment (medical applications)
– remote detection capability being developed
– THz spectroscopy
• Johns Hopkins University, US
– 'lab' equipment
– penetration up to 3cm in 'moist' sand(?)
• Other universities (e.g. Wisconsin-Madison, Leeds, Strathclyde)
– research only
[dstl]


THz - Pros and Cons
• Pros
– Very good resolution
– Reflects strongly from metal and dense materials
– 'Remote' detection possible
– Some material discrimination possible
– Health and Safety issues likely to be low - similar to mm-wave
• Cons
– Water/damp would attenuate the signal
– Current system expensive and only 'semi-portable'
– Limited penetration (no penetration of metal)
[dstl]


[dstl]
X-ray Imaging

Notes


X-ray Imaging - Basic Physics
• 10 keV - 10 MeV photons (10^{-10} - 10^{-12} m, 10^{18} - 10^{20} Hz).
• Conventional modes of imaging (mm resolution)
– Transmission (including stereoscopy, computed tomography).
– Scatter (including single-sided 'backscatter', diffraction).
• Material discrimination (dual energy or diffraction modes)
• Penetration
– very good in transmission (cm steel)
– limited in backscatter (due to scattering background from barrier)
• Health issues
– well known, requires lead shielding
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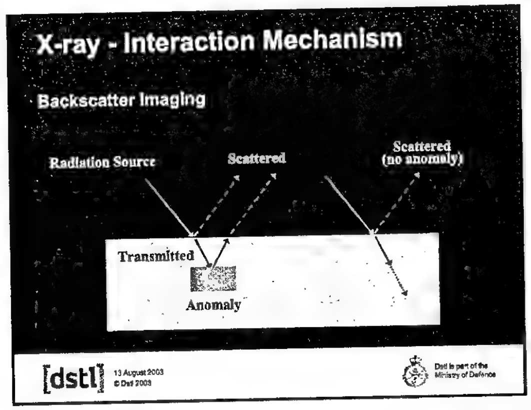
X-ray - Interaction Mechanism
• Backscatter Imaging
Radiation Source
Scattered
Scattered (no anomaly)
Transmitted
Anomaly
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X-ray - Applications
• Airport security:
– Baggage transmission imaging.
• Cargo screening:
– Transmission imaging for contraband / illegal immigrants.
• People screening:
– Backscatter imaging for concealed weapons / explosives.
• Mine detection:
– Backscatter imaging of explosive fill - confused by clutter and bright background signal.
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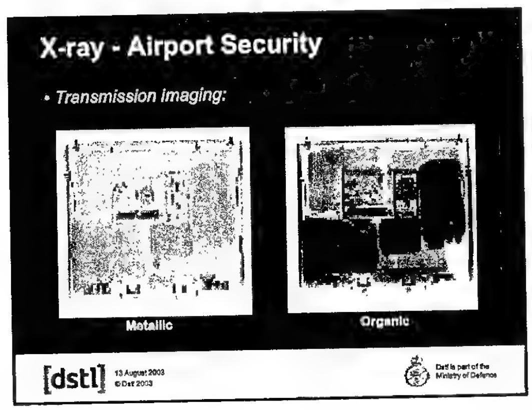
X-ray - Airport Security
• Transmission imaging:
Metallic
Organic
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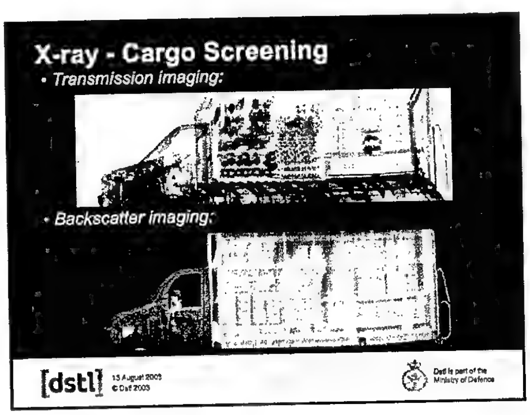
X-ray - Cargo Screening
• Transmission imaging:
• Backscatter imaging:
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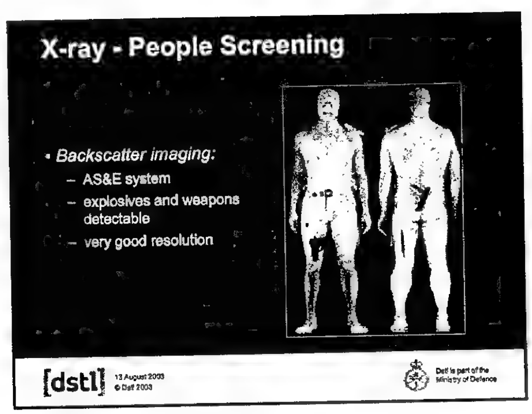
X-ray - People Screening
• Backscatter imaging:
– AS&E system
– explosives and weapons detectable
– very good resolution
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Notes

X-ray - Maturity

- *Many commercially available transmission systems:*
  - small-area digital imagers
  - large-area scanning (cargo systems)
- *Some commercially available backscatter systems:*
  - Not portable (bulky, heavy, not rugged).
  - Portability versus Health and Safety trade-off.
- *Future development areas:*
  - High-efficiency, flat-panel digital imagers, high-E X-ray tubes.
  - Compact backscatter imaging systems.

X-ray - Imaging Summary

- **People screening**
  - **Very good resolution & contrast for explosives and weapons**
  - **very low dose (in enclosed area)**
- **Mine detection?**
  - **Poor contrast against soil, clutter (e.g. rocks) - limited to shallow or surface mines**
- **General search**
  - **Not remote!**
  - **Limited use against building materials**

X-ray - Pros and Cons

• Pros	• Cons
• *Backscatter imaging:*	
– Good (5mm) spatial resolution.	– Limited image contrast against brick, concrete, thick steel (few mm), soil (few cm).
– Remote, one-sided access.	– 1/R⁴ image quality reduction.
– Imaging through metal	
– Health and Safety issues well understood.	
• *Transmission imaging:*	
– Good penetration through thick materials.	– Two-sided access required.

Acknowledgements

TeraView Ltd, Cambridge, UK

THz images and spectra

Questions?

THz detection of explosives and biologicals

Daniel VAN DER WEIDE, University of Wisconsin-Madison, USA

Electronic THz Imaging of Explosives

Daniel van der Weide
Associate Professor
Dept. of Electrical & Computer Engineering
University of Wisconsin-Madison

Acknowledgements: Min Choi, Fritz Keilmann, Janusz Murakowski, Vivek Agrawal, Scott Kee, Prayoot Akkaraekthalin, Björn Rosner

Support: FAA and Ford University Research Award; DARPA Ultra Electronics, ONR YIP, NSF PECASE

We will discuss our concept, progress and outlook for electronic THz sensors

- Nonlinear transmission lines (NLTLs)
- Coherent pulse generation/detection (equivalent-time sampling) systems
- Transmission spectroscopy of gasses
- Reflection spectroscopy of energetic materials
- Compact, integrated frequency translator for integrated coherent measurements

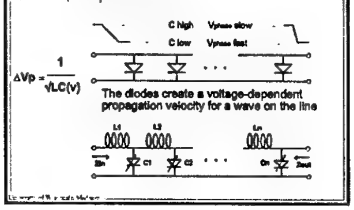
Our THz electronic spectrometer generates and detects picosecond pulses for wideband (1-1000 GHz) transmission and reflection spectra

- Sources based on microwave-pumped nonlinear transmission lines
  - Works like ultrafast laser-based systems, but without lasers
  - Upper frequency limit can reach THz regime
  - Pulse repetition rate is ~ 100 ps–wide harmonic spacing
  - Output power controllable
  - Harmonic frequencies tunable at ~ 1-10 Hz level
- Detectors: diode samplers integrated in same process as NLTLs, or use incoherent detectors
- Ultimately, the entire system could be a single IC with our new frequency translator

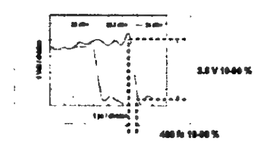
Needs, opportunities and applications

- Spectroscopic imaging for illicit substance detection, both as a portal and handheld
- Inexpensive microwave network analyzer, time-domain reflectometer
- Gas spectroscopy/sensing
- Subsurface imaging
  - Mine detection
  - Nondestructive evaluation of samples
- Testing phased-array radar in the field

Nonlinear transmission lines (NLTLs) create fast edges from sinusoidal inputs, and can also be used for frequency translation

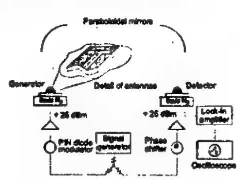


We currently fabricate NLTLs on GaAs that can produce < 1 ps edges

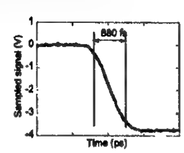


D.W. van der Weide, *APL* 65 (7) 881, 1994

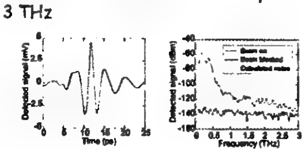
An electronic THz transmission spectroscopy system uses optical techniques to collect, focus, and collimate the radiation



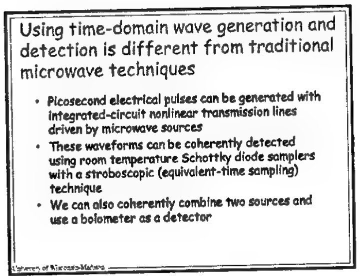
With a 3.5 V, 880 fs pulse at the generator antenna...

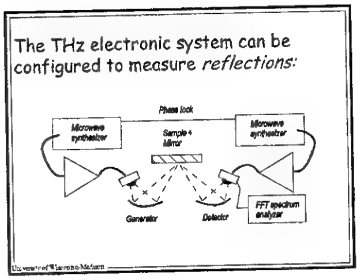


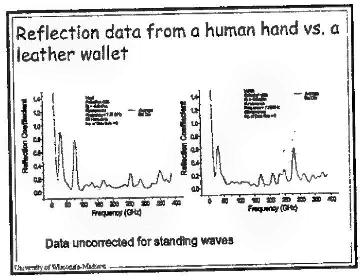
Freely-propagating pulses are seen at the detector with harmonics beyond 3 THz

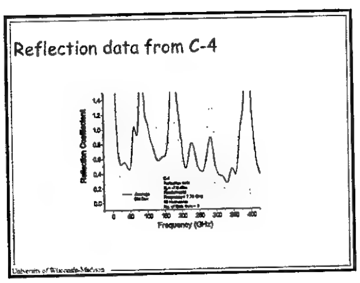


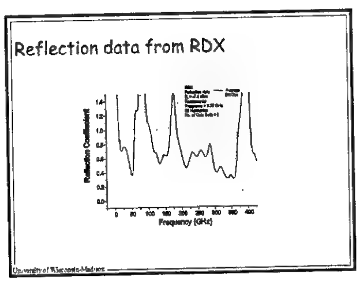
D.W. van der Weide, et al., *APL* 62, 22 (1993)

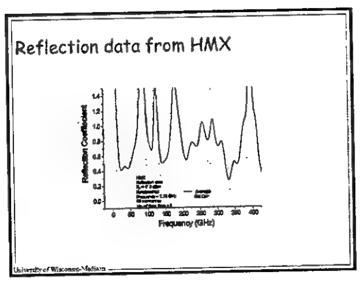

Using time-domain wave generation and detection is different from traditional microwave techniques
Picosecond electrical pulses can be generated with integrated-circuit nonlinear transmission lines driven by microwave sources
These waveforms can be coherently detected using room temperature Schottky diode samplers with a stroboscopic (equivalent-time sampling) technique
We can also coherently combine two sources and use a bolometer as a detector
University of Wisconsin-Madison

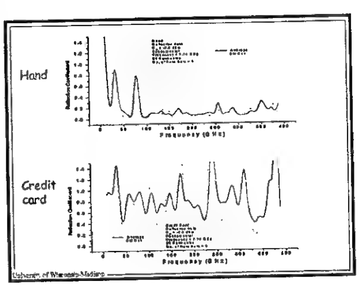

The THz electronic system can be configured to measure *reflections:*
Phase lock
Microwave synthesizer
Sample + Mirror
Microwave synthesizer
Generator
Detector
FFT spectrum analyzer
University of Wisconsin-Madison

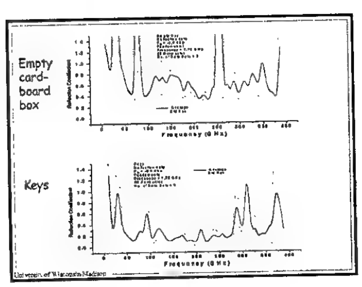

Reflection data from a human hand vs. a leather wallet
Reflection Coefficient
Frequency (GHz)
Data uncorrected for standing waves
University of Wisconsin-Madison

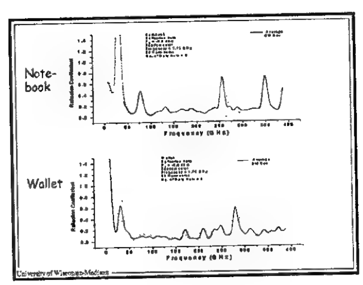

Reflection data from C-4
Reflection Coefficient
Frequency (GHz)
University of Wisconsin-Madison


Reflection data from RDX
Reflection Coefficient
Frequency (GHz)
University of Wisconsin-Madison


Reflection data from HMX
Reflection Coefficient
Frequency (GHz)
University of Wisconsin-Madison


Hand
Credit card
University of Wisconsin-Madison


Empty card-board box
Keys
University of Wisconsin-Madison


Note-book
Wallet
University of Wisconsin-Madison

THz systems can work as broadband reflection sensors in a hard-to-reach frequency regime

- Showed THz reflection spectra of several samples
  - Common objects
  - Energetic materials
- Results have identifiable spectra/unique signatures
- Cons of lab system:
  - Expensive synthesizers, amplifiers: Can use a new delay line frequency translator for THz systems on a chip
  - Total power < 100 microwatts: OK for handheld use but won't penetrate luggage at this level

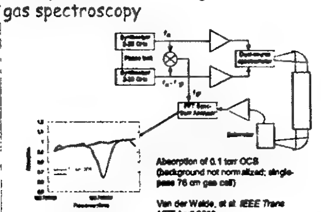
Microwaves have some advantages over traditional near- and mid-IR gas spectroscopy

Microwave
Usually very tunable
- Molecule must have permanent electric dipole moment
- Highly selective (~ 1 Hz possible in some cases)
- Radiation not scattered by particulates
- Traditionally very expensive and bulky equipment

Mid- and Near-IR
- Usually not tunable
- Vibrational or rotational absorption possible
- Quite broad; not very selective
- Radiation scattered by particulates
- Less expensive and lighter-weight equipment

Electronic THz system advantages
- Could be 1-3 IC's: inexpensive, compact and rugged
- Integrates directly with signal processing electronics
- Multi-species sensitivity
- Could be used in other areas, e.g. stacks, mines, etc.

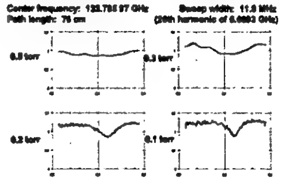
The system can be configured for gas spectroscopy



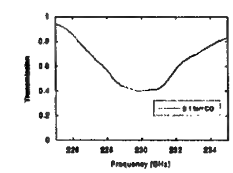
Absorption of 0.1 torr OCS (background not normalized; single-pass 76 cm gas cell)

Van der Weide, et al. *IEEE Trans MTT* April 2000

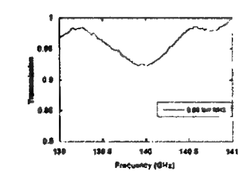
Microwave transmission measurements of OCS show pressure-broadening effect



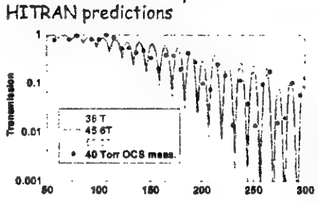
7.6 cm^{-1} CO line measured in swept frequency mode



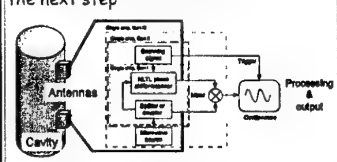
NH_3 line at 140 GHz also resolved



Broadband OCS absorption tracks HITRAN predictions



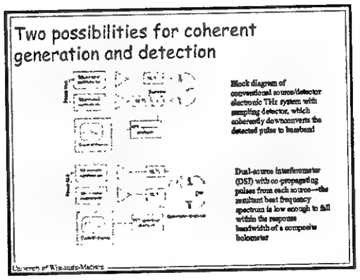
Integrating the demonstrated components onto 1-3 chips + cavity is the next step

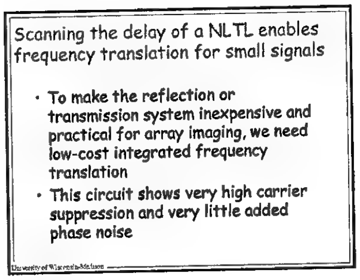


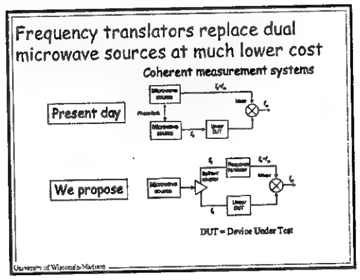
direct conversion of THz absorption spectrum to baseband

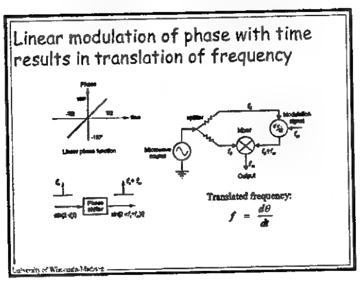
Conclusion: THz electronic sensor systems can address important security needs

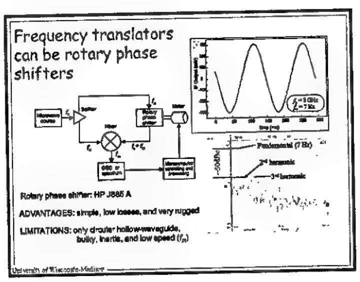
- THz electronics offer new sensing opportunities in a hard-to-reach spectrum
- Integrated circuits will lead to inexpensive sensors for a wide variety of applications
- Current systems are in GaAs, but could be realized in Si CMOS, as well

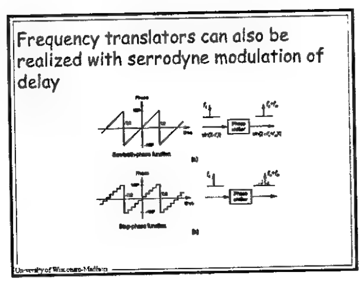

Two possibilities for coherent generation and detection
Block diagram of conventional source/detector electronic THz system with sampling detector, which coherently downconverts the detected pulse to baseband
Dual-source interferometer (DSI) with co-propagating pulses from each source—the resultant beat frequency spectrum is low enough to fall within the response bandwidth of a composite bolometer

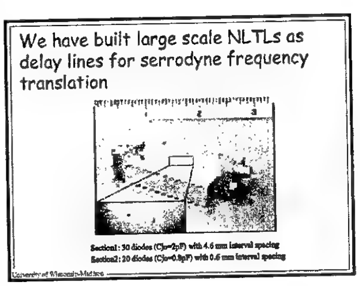

Scanning the delay of a NLTL enables frequency translation for small signals
• To make the reflection or transmission system inexpensive and practical for array imaging, we need low-cost integrated frequency translation
• This circuit shows very high carrier suppression and very little added phase noise

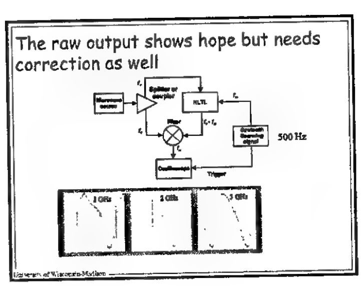

Frequency translators replace dual microwave sources at much lower cost
Coherent measurement systems
Present day
We propose
DUT = Device Under Test

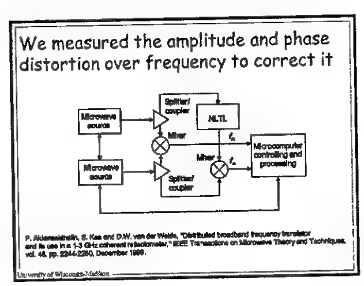

Linear modulation of phase with time results in translation of frequency
Linear phase function
Translated frequency:
$f = \frac{d\theta}{dt}$

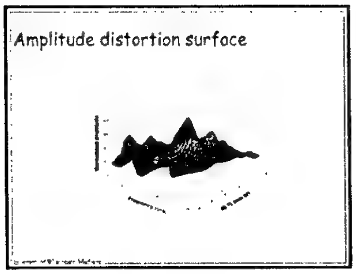

Frequency translators can be rotary phase shifters
Rotary phase shifter: HP J885 A
ADVANTAGES: simple, low losses, and very rugged
LIMITATIONS: only circular hollow-waveguide, bulky, inertia, and low speed

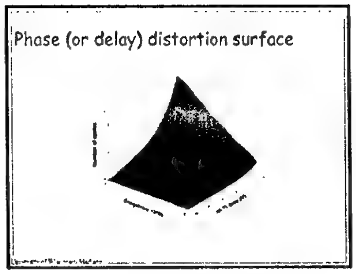

Frequency translators can also be realized with serrodyne modulation of delay

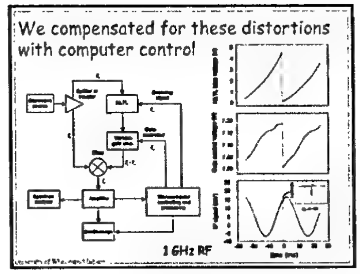

We have built large scale NLTLs as delay lines for serrodyne frequency translation

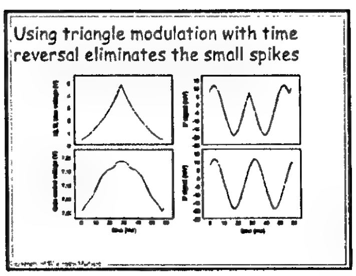

The raw output shows hope but needs correction as well
500 Hz
1 GHz
2 GHz
3 GHz

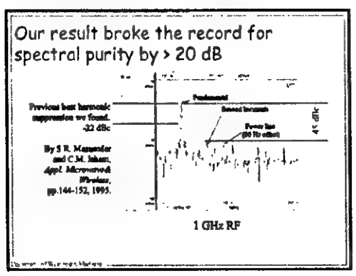

We measured the amplitude and phase distortion over frequency to correct it
Microwave source
NLTL
Mixer
Microcomputer controlling and processing

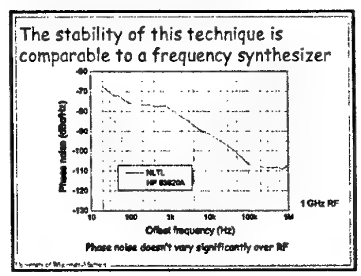

Amplitude distortion surface

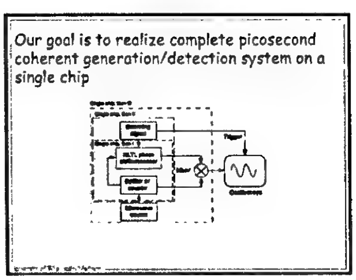

Phase (or delay) distortion surface

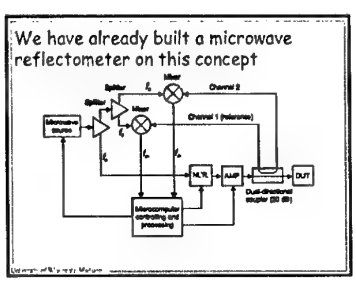

We compensated for these distortions
with computer control
1 GHz RF

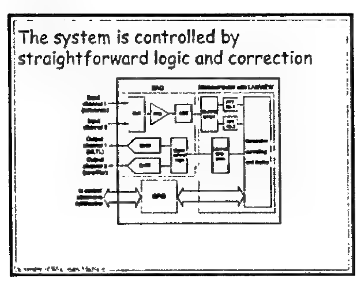

Using triangle modulation with time
reversal eliminates the small spikes


Our result broke the record for
spectral purity by > 20 dB
1 GHz RF


The stability of this technique is
comparable to a frequency synthesizer
Offset frequency (Hz)
1 GHz RF
Phase noise doesn't vary significantly over RF

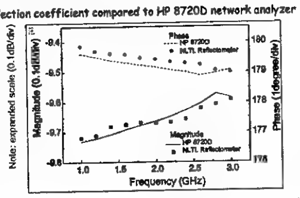

Our goal is to realize complete picosecond
coherent generation/detection system on a
single chip


We have already built a microwave
reflectometer on this concept

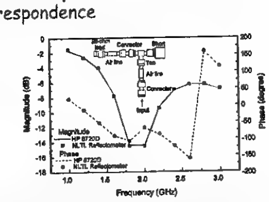

The system is controlled by
straightforward logic and correction

The result from a 25Ω load almost exactly corresponds to a commercial instrument

Reflection coefficient compared to HP 8720D network analyzer



An arbitrary load also shows excellent correspondence



Akkaraekthalin, Kee, and van der Weide, *IEEE Trans MTT* December 1998

The frequency translator performed well in its first system application

- We proposed a new reflectometer using a heterodyne technique with the distributed frequency translator
- We analyzed the error correction for the reflectometer
- We designed and built an *inexpensive* automatic reflectometer controlled by a PC
- Excellent correspondence with a commercial network analyzer (HP 8720D)

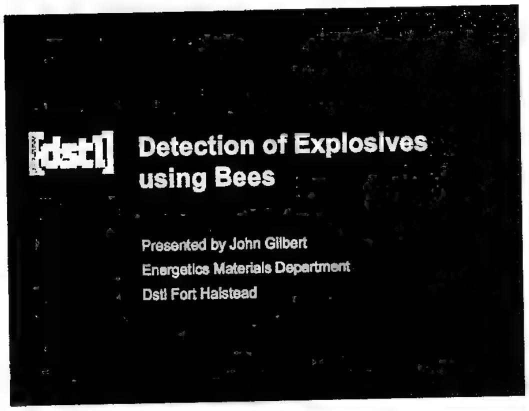
Future work for the frequency translator

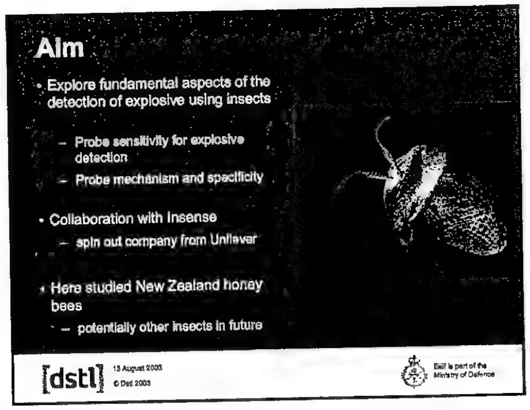
- Increase bandwidth of frequency translator by using new devices and structure of the NLTL
- Integrate several parts into an IC (MIC or MMIC)
- Improve control and bias circuits for increasing carrier and sideband suppression and lowering phase noise, *i.e.* high-speed circuits
- Develop hardware/software to increase the accuracy and speed of the NLTL reflectometer
- Develop new applications, *i.e.* an *inexpensive* full two-port network analyzer, gas sensor, etc.

Vapour detection and canine/bee olfaction

John GILBERT, DSTL Fort Halstead, UK

Notes


[dstl]
Detection of Explosives using Bees
Presented by John Gilbert
Energetics Materials Department
Dstl Fort Halstead


Aim
• Explore fundamental aspects of the detection of explosive using insects
– Probe sensitivity for explosive detection
– Probe mechanism and specificity
• Collaboration with Insense
– spin out company from Unilever
• Here studied New Zealand honey bees
– potentially other insects in future
[dstl] 13 August 2003
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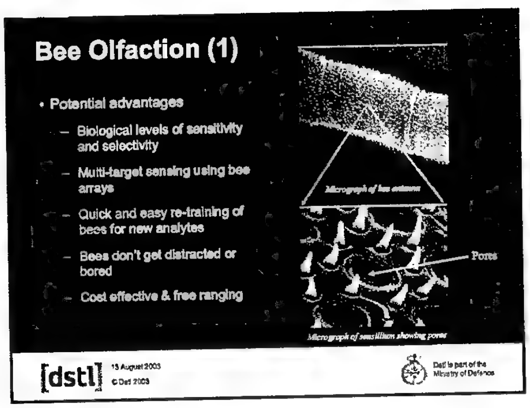
Bee Olfaction (1)
• Potential advantages
– Biological levels of sensitivity and selectivity
– Multi-target sensing using bee arrays
– Quick and easy re-training of bees for new analytes
– Bees don't get distracted or bored
– Cost effective & free ranging
Micrograph of bee antenna
Pores
Micrograph of sensillium showing pores
[dstl] 13 August 2003
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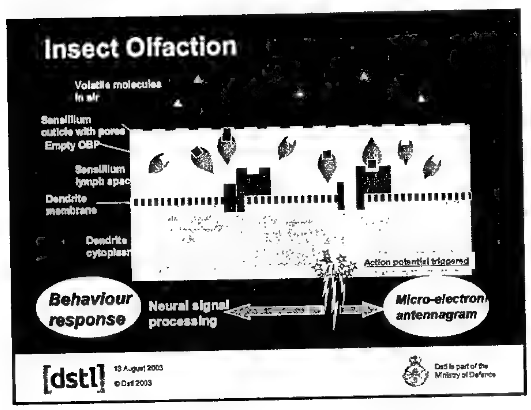
Insect Olfaction
Volatile molecules in air
Sensillium cuticle with pores
Empty OBP
Sensillium lymph spac
Dendrite membrane
Dendrite cytoplasr
Action potential triggered
Behaviour response
Neural signal processing
Micro-electron antennagram
[dstl] 13 August 2003
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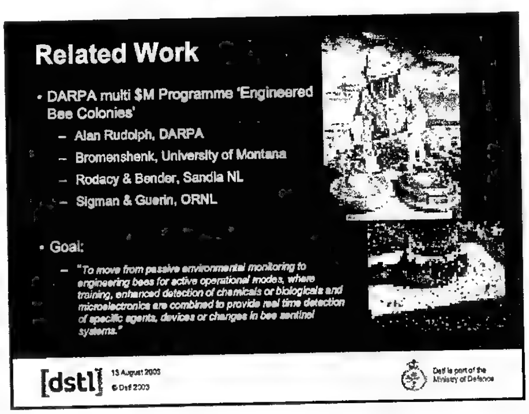
Related Work
• DARPA multi $M Programme 'Engineered Bee Colonies'
– Alan Rudolph, DARPA
– Bromenshenk, University of Montana
– Rodacy & Bender, Sandia NL
– Sigman & Guerin, ORNL
• Goal:
– "To move from passive environmental monitoring to engineering bees for active operational modes, where training, enhanced detection of chemicals or biologicals and microelectronics are combined to provide real time detection of specific agents, devices or changes in bee sentinel systems."
[dstl] 13 August 2003
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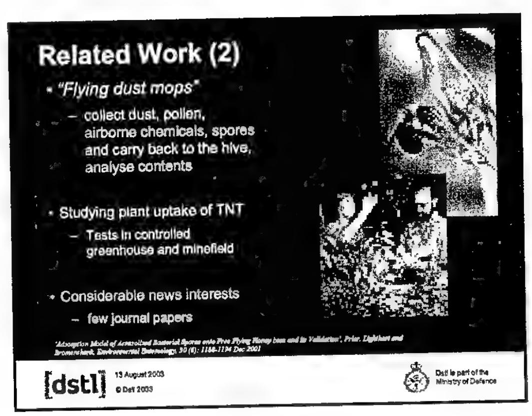
Related Work (2)
• "Flying dust mops"
– collect dust, pollen, airborne chemicals, spores and carry back to the hive, analyse contents
• Studying plant uptake of TNT
– Tests in controlled greenhouse and minefield
• Considerable news interests
– few journal papers
'Adsorption Model of Aerosolized Bacterial Spores onto Free Flying Honey bees and its Validation', Prier, Lighthart and Bromenshenk, Environmental Entomology, 30 (6): 1188-1194 Dec 2001
[dstl] 13 August 2003
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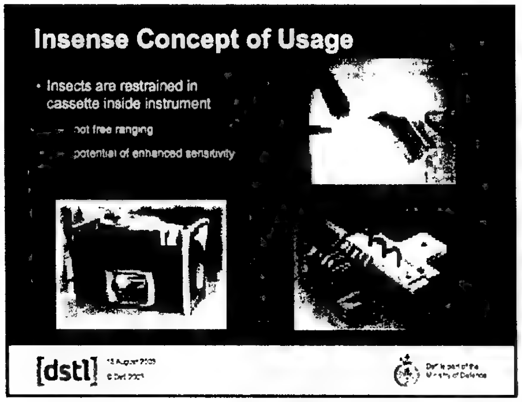
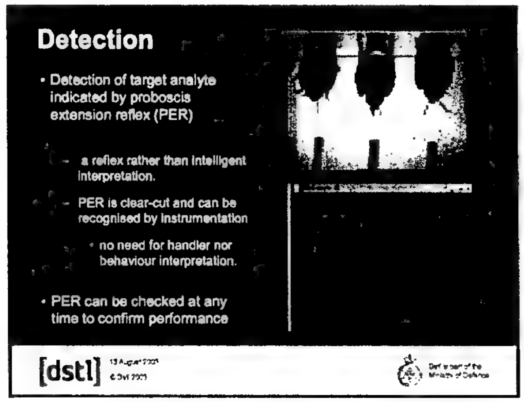
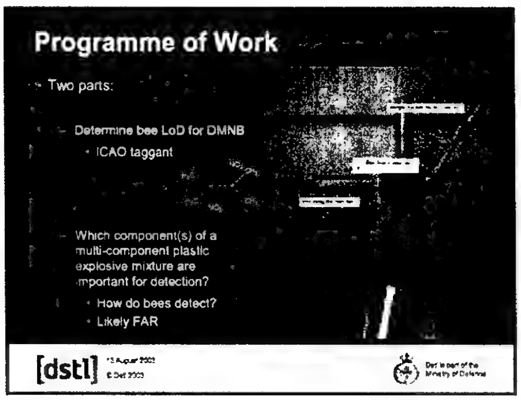
Notes



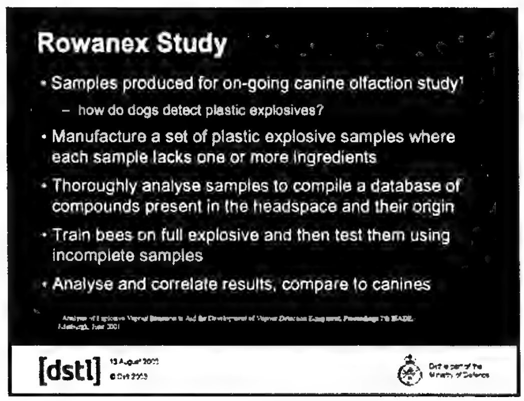
Insense Concept of Usage
• Insects are restrained in cassette inside instrument
– not free ranging
– potential of enhanced sensitivity
[dstl]



Detection
• Detection of target analyte indicated by proboscis extension reflex (PER)
– a reflex rather than intelligent interpretation.
– PER is clear-cut and can be recognised by instrumentation
• no need for handler nor behaviour interpretation.
• PER can be checked at any time to confirm performance
[dstl]



Programme of Work
• Two parts:
– Determine bee LoD for DMNB
• ICAO taggant
– Which component(s) of a multi-component plastic explosive mixture are important for detection?
• How do bees detect?
• Likely FAR
[dstl]

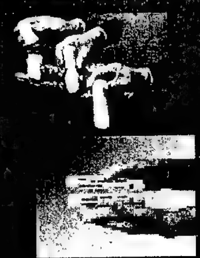


Rowanex Study
• Samples produced for on-going canine olfaction study[1]
– how do dogs detect plastic explosives?
• Manufacture a set of plastic explosive samples where each sample lacks one or more ingredients
• Thoroughly analyse samples to compile a database of compounds present in the headspace and their origin
• Train bees on full explosive and then test them using incomplete samples
• Analyse and correlate results, compare to canines
[dstl]

Notes

Composition of Rowanex 4100

- Rowanex 4100 plastic explosive comprises:-
  - RDX 88%
  - Binder 11.5%
  - Anti-oxidant (AO) 0.06%
  - Binding agent 0.4%



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Results - DMNB LoD

- Bees readily conditioned to odour from DMNB from quantities 1 ug - 100 mg
- Lowest concentration bees responded to was 20,000x dilution
  - 15.8/20,000 ug/l = 790 pg/l
  - assume ideal gas,
    - 1 mole (178g) DMNB occupies 24.3 L @ 25 °C i.e. 7.2g/l
    - $0.79/7.2 \times 10^9 = 110$ ppt_v

* Saturated DMNB vapour 15.8 ug/l @ 25 °C

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Results - Accuracy of Static Method

- Accuracy of static method measured
  - Tenax tube inserted in place of bee, analysed by GC/MS
- Theoretical amount expected generally underestimated
- Large variability : 110 ± 73.7 ppt_v, range 183.7 - 36.3 ppt_v

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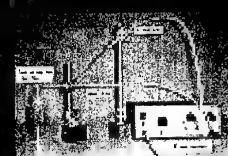
Results - Dstl pulsed vapour generator

- Dstl vapour generator replaced Insense pulse generator
  - 10s pulse 700 ml /min^{-1}, added to 1.3 l/min^{-1} make up flow
    - @ 25 °C, 1:20,000 dilution
    - @ 30 °C, 1:5,000 dilution
  - No bee response at 1:20,000 dilution (110 ppt_v)
  - 10% bees responded at 1:5,000 (438 ppt_v)
- Results conducted with different bees



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Results - Rowanex Study

- Bees could be conditioned to detect Rowanex
  - more rigorous process required however

	Dilution factor* of SRV (the flow through flow-meters FM2 / FM3 of the dynamic system is shown in brackets)					
	4.9 (0 / 500)	9.8 (250 / 250)	20.5 (400 / 100)	40 (450 / 50)	79 (475 / 25)	157 (490 / 10)
% of bees responding to the dilution of SRV	95.4	90.9	59.1	31.8	13.6	0

* Dilution factor X corresponds to a mixture containing 1 part of SRV and (X-1) parts of pure air. The final dilution of SRV was calculated from the dilution of flow FM3 into the main flow (1950 mL min^{-1}). For example: (1950+100)/100 = 20.5 (see above).

- 'Standard Rowanex Vapour' (SVR)
  - Vapour generated from ~150 mg Rowanex in continuous flow of 0.5 ml/min^{-1}
  - Detectable down to dilutions 1/80th of SVR

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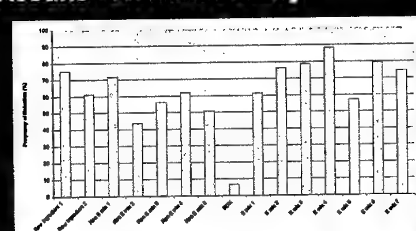
Results - Rowanex Study



- All components contained a common binder
  - If bees keying on this component, can be desensitised to ignore it

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Notes

Conclusions

- Bees can be trained to detect synthetic explosives and taggants
  - DMNB and Rowanex 4100
- Indicative LoD for DMNB ~ 110 ppt
  - impressive but not startling, comparable to instruments
    - Insense confident this can be improved
- Bee appears to be keying in on a small number of odours
  - not as sophisticated pattern recognition machines as dogs

Way Forward

- Considerable further fundamental work required to understand insect olfaction
  - underpins all applications
- Free ranging bees more attractive applications
  - LoD not only factor in determining whether insect finds target or not
  - LoD's not sufficiently impressive to overcome practical issues associated with 'bee-in-a-box'.

Acknowledgements

- John Wilkins INSENSE
- David Groves DSTL

Questions?

"However, bees are pretty damn lazy, really. If there is something else more tempting on offer, they will go for that instead" Richard Jones, International Bee Research Association

"Its important to look after them [bees], as they only work if they're totally happy and comfortable." Prof Paul David, Insense

An overview of the APOPO program, rats for landmine detection
Christophe COX, APOPO, Belgium

The APOPO project is training rats for the detection of landmines. The rats are trained to indicate the presence of explosive vapours, and are rewarded upon with food. The animals are both trained for direct detection of the location of the buried landmine, as well for the detection of explosive vapours in air samples.

APOPO, a Belgian research organisation, started looking for a cheap and efficient landmine detection technique from 1997. After a feasibility study of two years in Belgium, the whole project shifted toward the Sokoine University of Agriculture, in Morogoro, Tanzania, where the training methodology and detection technologies were further developed. At this moment, APOPO is training over 100 rats daily and has a total capacity of over 300 animals.

One of the main reasons for using rats is their highly developed sense of smell. Moreover, they are very trainable, cheap and easy to maintain. With an initial focus on the African landmine problem, APOPO choose the '*Cricetomys gambianus*' or Giant African Pouched Rat for the landmine detection task. This rat has the additional advantage of being a relatively calm animal and has a lifespan up to eight years.

For direct detection, APOPO has a 28 ha test and training field, with over 1000 mapped landmines. Currently, the rats are trained on 100m^2 boxes, which they search in 28 minutes on average. The rats are attached with a leash to a search bar, which makes them to search in 0,5 meter lanes, moving forward progressively.
First tests are being carried out in Mozambique in co-operation with MgM and NPA. APOPO is expecting the go ahead of the national demining authorities to work on sharp mines by next month.

For Residual Explosive Scent Tracing (REST), the rats evaluate filters drawn from above the suspected minefield on the occurrence of explosive traces. The purpose of the REST technology is to quickly scan big suspected areas and release the mine free land. APOPO has developed some evaluation set-ups, in which a rat evaluates 150 filters in 20 minutes. In collaboration with GICHD, APOPO is also investigating which factors influence the availability and spread of the explosive vapour, such as climatic and environmental factors. Also different types of filters are being tested within this program. This research will allow the documentation of this technology, where and under which circumstances it can be used with adequate reliability.

Apart from demining, vapour detection by rats has a series of other potential applications, both in the medical, environmental, transport and security sectors. The rat is one of the most sensitive animals to any kind of vapour compared with other technologies currently available.

Neutron Resonance Radiography for Security Applications

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Massachusetts Institute of Technology, USA

ABSTRACT

Fast Neutron Resonance Radiography (NRR) has been devised as an elemental imaging method, with applications such as contraband detection and mineral analysis. In the NRR method, a 2-D elemental mapping of hydrogen, carbon, nitrogen, oxygen and the sum of other elements is obtained from fast neutron radiographic images taken at different neutron energies chosen to cover the resonance cross section features of one or more elements. Images are formed using a lens-coupled plastic scintillator-CCD combination. In preliminary experiments, we have produced NRR images of various simulants using a variable energy neutron beam based on the Li(p,n)Be reaction and a variable energy proton beam. In order to overcome practical limitations to this method, we have studied NRR imaging using the D-D reaction at a fixed incident D energy and scanning through various neutron energies by using the angular variation in neutron energy. The object-detector assembly rotates around the neutron source and different energy (2-6 MeV) neutrons can be obtained at different angles from a D-D neutron source. The radiographic image provides a 2-D mapping of the sum of elemental contents (weighted by the attenuation coefficients). Transmission measurements taken at different neutron energies (angles) form a set of linear equations, which can then be solved to map individual elemental contents.

Keywords: Neutron radiography, imaging fast neutron, aircraft security, explosive detection, contraband detection

1. OVERVIEW

The problem of aircraft security has had renewed interest and urgency since the events of September 11, 2002. The problem of explosive and contraband detection has been extensively studied [1]. Current technology for checked baggage inspection has centered on the use x-ray CT as the screening technique of choice with the use of trace detectors as a confirmatory measurement. Air cargo remains a more difficult task due to the size of the containers and this has led to the idea of a combination of trusted shippers and breaking out of cargo into individual (smaller) objects for screening. Although CT is a powerful technique, the results of initial field deployment were plagued by false alarms and ambiguous results. Part of this was due to the normal expected problems of deployment of new technology and part was inherent in the use of x-ray technology.

The basis for any inspection technique is a method for discerning the difference between common materials and the rare presence of explosive materials. Since common materials are the norm, it is important that the trade-off between sensitivity and specificity be carefully defined so as to avoid excess numbers of false alarms which will not only waste time and money but, if too high, will also create a chaotic situation in the airport. X-rays are currently used to determine apparent density of materials and, with less sensitivity, the average atomic number of materials. With respect to the issue of sensitivity, most common explosives contain high concentrations of nitrogen and oxygen but there are non-nitrogenous explosives as well, some of which have been used in the recent past, such as TATP, with a density of ~1.2 and no nitrogen.

A more vexing problem is in specificity; when only density is measured; many common materials such as sugar, chocolate, marzipan, honey, jams and jellies may look like explosives to x-rays. Figure 1 shows the density and average atomic number of many explosives and several more common materials found in luggage. With conventional, single energy spectrum x-ray CT systems, only the apparent density may be determined; with dual energy systems, some information about the average atomic number may also be obtained. Although average atomic number may be a useful

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number, it does not directly give information about the elemental composition of materials. If elemental composition is to be determined, nuclear techniques offer the most straightforward way to make measurements of the elemental and spatial distributions of the contents of containers.

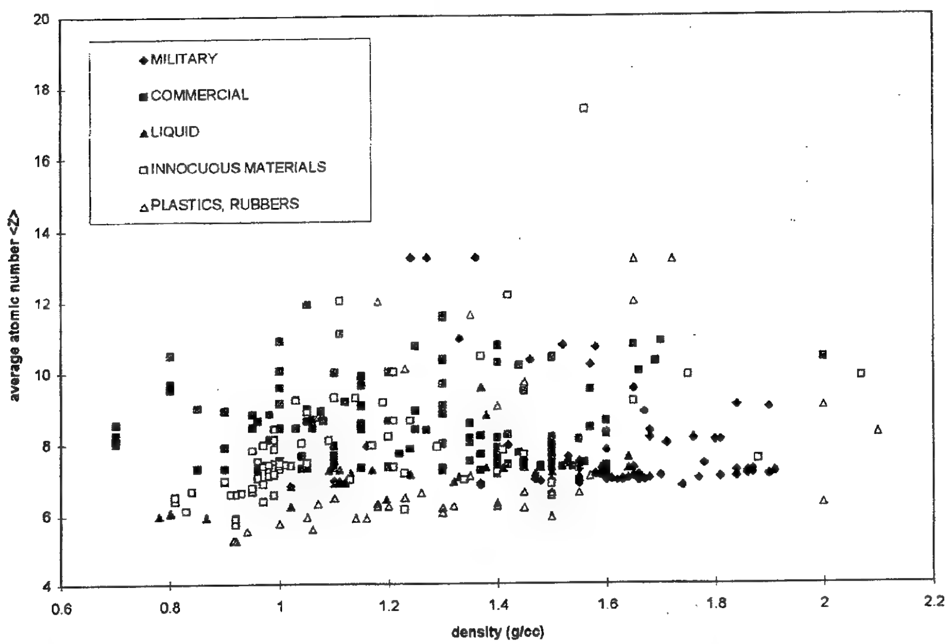

Figure 1 Relationship between average atomic number and density for selected materials. Note the concentration of relatively high density and average atomic number between 7 and 8 for military explosives [2].

The advantages of nuclear techniques, in particular those using neutrons as probes, are well known and may be summarized as follows:

- Determination of elemental composition, not just density
- Great penetration for dense objects or for cargo inspection
- Difficult to shield contraband from probing radiation

Unfortunately, these very advantages also have their corresponding disadvantages in practice:

- Elemental composition often means only nitrogen determination
- Great penetration requires significant shielding for use in an airport or seaport applications
- They generally are based on accelerator technologies which may be large and expensive

For example, Figure 2 shows the density and nitrogen fraction for various materials. Although nitrogen content is generally high for explosives, there still is a significant overlap with ordinary materials. Nitrogen alone is not usually a sufficient discriminate to avoid false alarms, especially if the system does not have sufficient spatial resolution to determine nitrogen *density*. For example, ordinary air has a nitrogen density of 1.2 Kg/m^3 and there is sufficient nitrogen from the air in a large suitcase to be comparable to that in a threat quantity of explosive. It is usually necessary to have measurements of several elements to more unambiguously discriminate threat materials from ordinary materials. Figure 3 shows the distribution of nitrogen and oxygen in a large number of explosives and illustrates the potential power of elemental composition measurements. Other elements that are relevant for improving specificity are carbon

and hydrogen. Thus, a system with the ability to produce spatially resolved elemental composition images would have greatly enhanced specificity in the determination of potential threats.

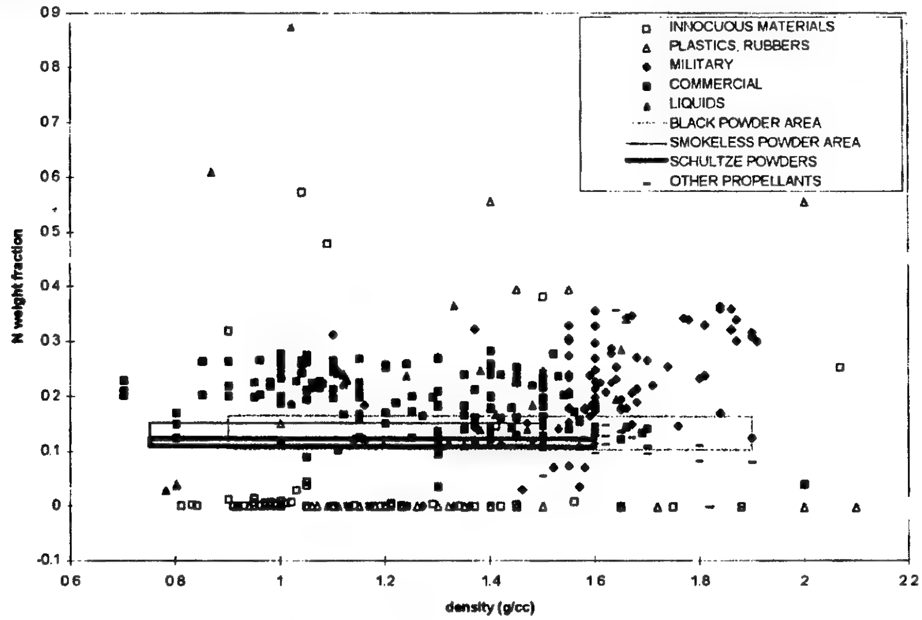

Figure 2 Relationship between density and nitrogen fraction for various materials. Although nitrogen content is generally high for explosives, there still is a significant overlap with ordinary materials [2]

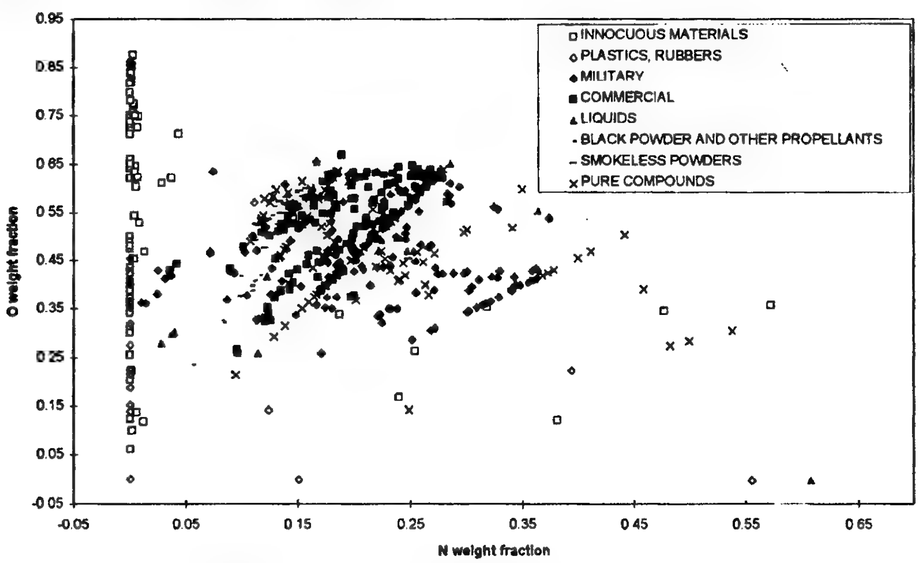

Figure 3. Relationship between nitrogen and oxygen densities for various materials. Note that many military explosives are concentrated in a narrow region of high oxygen content and high nitrogen content [2].

2. NEUTRON RESONANCE RADIOGRAPHY

Neutron Resonance Radiography (NRR) utilizes the element specific resonances in total neutron attenuation cross-sections, in our case in the 1 to 8 MeV range, which are exploited to enhance the contrast for imaging light elements such as carbon, oxygen and nitrogen. The goal of this work is to utilize this contrast enhancement mechanism to produce elementally resolved images of objects under inspection and to have sufficient penetration so that thick objects may be imaged.

A straightforward way of doing neutron resonance radiography is to map one element at a time. At an energy region with a resonance peak or valley for one element where the cross sections of other elements are flat over the same energy range, we take radiographic images at on-resonance energy and off-resonance energy and then compute the pixel-by-pixel difference of the two images. Early work in this area for the detection of explosives was reported by a group in South Africa using the National Accelerator Centre van der Graaff to explore the low energy resonances in nitrogen. Nitrogen is characterized by a very narrow peak at 433 keV as is seen in Figure 4, but this group was able to clearly image explosives and separate them from ordinary materials for small samples [3].

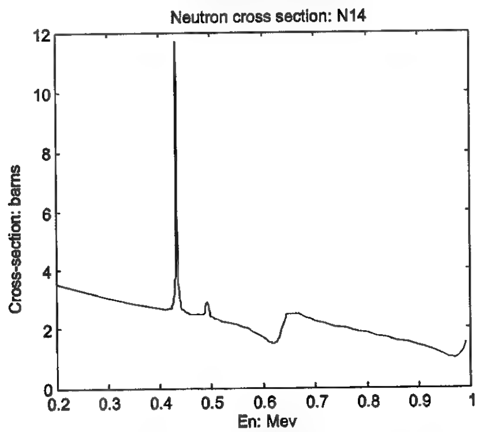

Figure 4. Nitrogen cross-section in the low energy region

As will be discussed later, the use of low energy resonances has several major difficulties in practice. If higher energies are used, some of these problems may be overcome. With a mono-energetic neutron source, one can map one element at a time, looking for an energy region with a resonance peak/valley for one element while the cross sections of other elements are flat over the same energy range. For example, referring to Figure 5 which shows the cross-section for carbon in the 0.5 to 10 MeV range, we might choose the sharp resonance peak at 2.077 MeV for carbon or the relatively broad peak in the 7 to 8 MeV range.

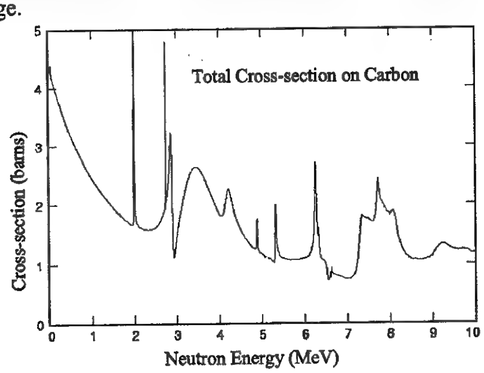

Figure 5. Resonance structure for carbon in the 0.5 to 10 MeV range

A radiographic image is taken on-resonance, and another taken off-resonance; the difference of the two images gives a 2-D map of the corresponding element. In the case of imaging only carbon, the broad peak in the 7 to 8 MeV range is more useful since the width of the peak is so much larger and thus a thicker target can be used.

3. FAST NEUTRON PRODUCTION

The most common way of producing fast neutrons for radiography is through nuclear reactions using a particle accelerator and a target. Two reactions were used in our preliminary experiments and in subsequent simulations; the (endothermic) reaction $p + {}^{7}Li \rightarrow {}^{7}Be + n$ and the (exothermic) reaction $D + D \rightarrow {}^{3}He + n$. The p-^{7}Li source has slower energy fall-off with neutron angle than the D-D source, so it is a better mono-energetic neutron source for imaging applications with a single element. With energy falling off at increasing angle, different parts of the image will experience different energy neutrons, which is important if the imaging method requires mono-energetic neutrons, such as NRR with single peaks. The applicable angles beyond which the object should not extend are 10° and 5° for both sources, respectively. In addition, the p-^{7}Li source is usually contaminated with gamma rays while the D-D source is generally not.

In order to examine the potential of this method for detection of other elements, we examined the energy range from 1.5-2.5 MeV and used the peaks shown in Figure 6. Experiments were carried out using a p-^{7}Li neutron source with a 2 to 6 MeV proton beam from the University of Massachusetts (Lowell) Van de Graaff accelerator. Neutron yield was about $5x10^{7}$ neutrons/sr/s at 0° with typical proton currents of 5-10 μA. Resonance peaks are typically 10-30 keV in width, requiring a thin target for mono-energetic neutron generation.

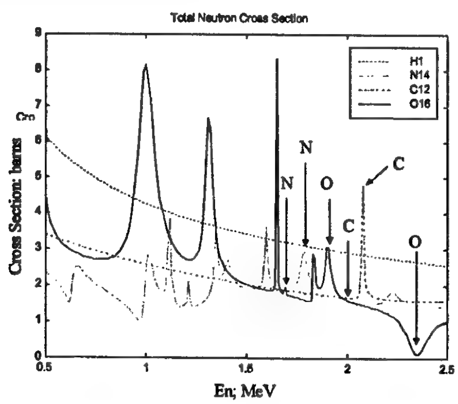

Figure 6. Peaks in the 0.5 to 2.5 MeV range that were investigated for neutron resonance radiography

The transmitted neutrons were imaged using the camera system of Figure 7 [4]. The imaging system uses a single large piece of plastic scintillator as a detector, providing reasonable efficiency without significant loss of resolution. Since the detection system uses a lens-coupled detector, the spatial resolution is limited by a combination of parallax and depth of focus [5].

Figure 8 shows images taken of a series of test objects: drug simulant (top left), explosive simulant (bottom left), graphite powder (top right) and melamine (bottom right), in 35 mm photographic film containers. The axes are in units of pixels, each pixel is about 0.5 mm. The source-object distance was ~30 cm and object-detector distance was ~15 cm. The objects are within a 10° beam cone. (S1=~30 cm, S2=~15 cm, θ< 10°)

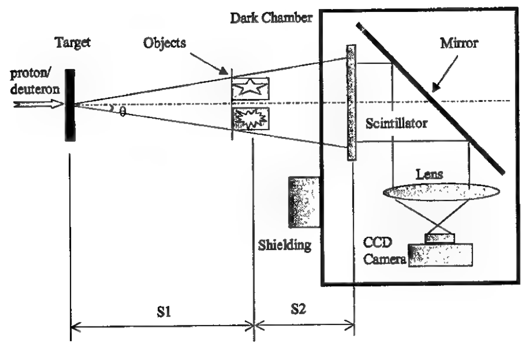

Figure 7. Scintillation camera used for imaging experiments

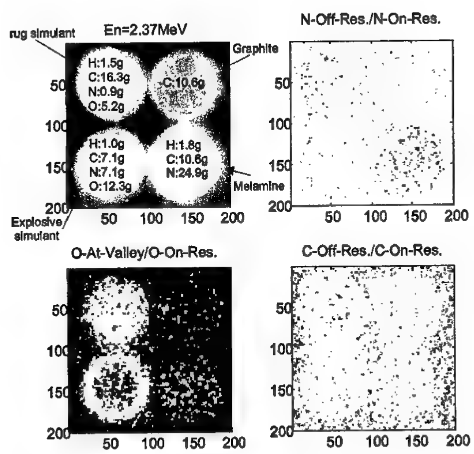

Figure 8. NRR with single peaks (a) image at 2.37 MeV, (b) nitrogen on and off resonance, (c) oxygen on and off resonance, (d) carbon on and off resonance.

The simple method employed here has several significant problems in practical applications. First, we note that single, distinct resonance peaks are usually found in the 0.5-2.5 MeV neutron energy region, where the total neutron cross section (especially that of hydrogen) is large and therefore neutron penetration is poor. Second, since the resonance peaks are typically 10-30 keV in width, a thin target is required to maintain a beam of essentially mono-energetic neutrons. Such thin targets, especially using lithium, have thermal problems, which generally limit the beam current and thus the neutron output. Third, a relatively small viewing angle ($\theta<10°$) is required so that the neutron energy fall-off across the image is significantly smaller than the difference between on and off resonance energy, restricting the geometry. Finally, different energy neutrons are obtained by changing the accelerator energy, an undesirable requirement in inspection applications where high throughput is required, since for large electrostatic accelerators, the terminal voltage cannot be changed in fractions of a second. For some applications, such as the minerals industry, where only a single element is being detected, the single peak approach is considerably more practical as it is possible to use a pair of radiofrequency quadrupole (RFQ) accelerators to move rapidly between two energies [6]. With this exception, the single peak implementation has practical limitations but does demonstrate the technique.

As previously discussed, detection of nitrogen alone does not determine the presence of explosives and contraband and thus extensions to permit multiple element detection are required. Unfortunately, it becomes difficult to find distinct resonance peaks for all elements of interest and, in addition, neutron resonance radiography with distinct resonance peaks suffers from the practical problems discussed previously. To improve the method, we have investigated the broad resonance structure at neutron energies of 2 to 6 MeV, and have developed an approach based on the use of the broad structure in this energy range rather than requiring a narrow energy spread beam. In effect, all elements will be imaged simultaneously without changing the accelerator energy.

Other groups have used similar principles, based on neutron time-of-flight (TOF) and also applied them to non-destructive inspection for the detection of explosives and other contraband in baggage and cargo [7]. Our method does not use TOF and thus does not require a pulsed (~ ns) neutron source with a relatively long (~3 m) flight path and thus can be made more compact than these systems. Since there is no need for a long flight path, there is sufficient room to place the detector far enough from the object so that it is possible to reduce scattering in the images as well and thus to improve contrast. (The optimum geometry is when the object is halfway between the source and the detector.) Further, since the detector is only a simple integrating imager, it is possible to obtain considerably better spatial resolution (~ 3 mm) as compared to detectors in which each pixel must be instrumented, limiting individual pixel resolution to 3 cm or more

In our approach, we also generate all energies simultaneously but do so by using the kinematics of the DD reaction, where the neutron energy depends on the angle between the incident beam and the emitted neutron. This is illustrated in Figure 9 where the energy of the emitted neutron is shown as a function of neutron angle. Three curves are shown, which correspond to the spread of energy expected in a target 600 keV thick with a 2.3 MeV incident deuteron beam energy.

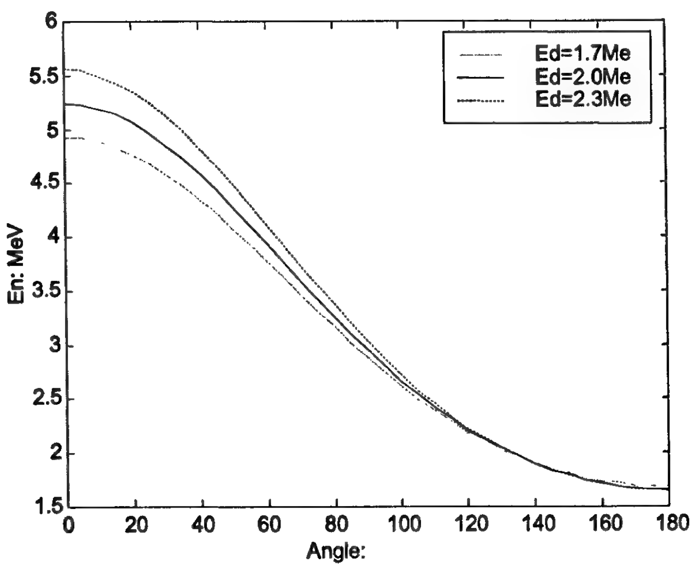

Figure 9. Energy of neutron resulting from the DD reaction at 1.7 to 2.3 MeV incident energy deuteron.

We now can scan through the energies of the resonances by moving the object under inspection around the target; as the angle changes the energy changes as in Figure 9. It should be noted that due to the thick target and the finite acceptance angle at the detector, a relatively wide range of energies is scanned at any angle. The method is analogous to spectral fitting methods for determining elemental composition through gamma spectroscopy where detectors with relatively

poor spectral resolution are used but the resulting spectrum is fitted to a series of low-resolution spectra from individual elements. In this technique, the entire absorption spectrum is utilized and therefore the use of the neutrons is very efficient as compared to monoenergetic single energy scanning. The problem is reduced to considering an equivalent transmission spectrum for each element and fitting the observed spectrum to a linear combination of these equivalent transmission spectra. The basic method is straightforward: a series of images is taken at multiple angles (energies) and the resulting data set is fitted on a pixel-by-pixel basis to a particular combination of elements. The details of various computational methods for accomplishing this have been published in several places [7,8,9]. For carbon, oxygen, nitrogen, and hydrogen, the appropriate spectra are shown in Figure 10.

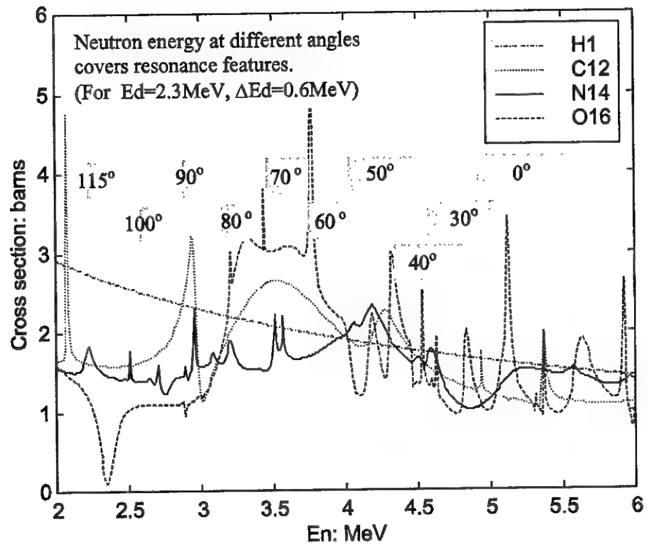

Figure 10. Spectrum of energies scanned. The shaded areas are the range of energies at a particular nominal neutron angle.

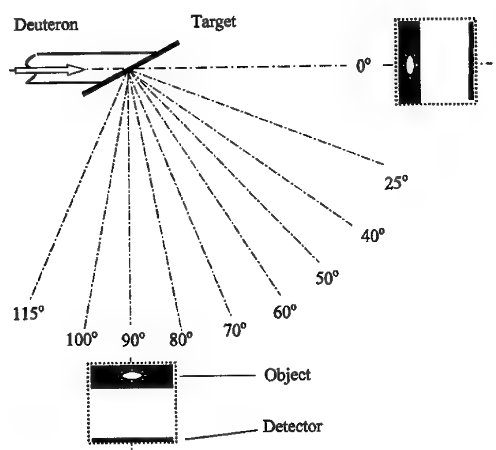

Figure 11. One possible approach to scanning baggage. The baggage is moved in a circular path centered on the deuterium target.

A practical way of implementing this is shown in Figure 11. The luggage is moved along a conveyer belt around the target. Bags are shown on one side, but a second path could also be added on the other side of the target to double throughput.

Typically the neutrons are generated by bombarding a deuteron target with energetic deuterons accelerated by a fixed energy commercially available Radio Frequency Quadrupole (RFQ) accelerator [10]. The major advantage of the RFQ in this application is that it is compact (~ 1 m long) and capable of high current operation (~ 140 μA average). The fixed energy inherent in the RFQ, is not a disadvantage in this application since we use the angular dependence of the neutron energy to vary energy. The target design depends on the final system parameters especially the beam diameter and current. In previous work we have reported on the design of a windowless gas target capable of operation at 3 to 6 atmospheres and capable of handling a beam diameter of ~ 2mm. We estimate that systems capable of scanning baggage in the 6 s time scale would require beam currents of ~10 μA with a nominal target of 6 atmosphere-cm of D_2 depending on the details of the detector efficiency and nominal pixel size.

4. SIMULATIONS

In order to study the process in more detail, a series of simulations were made using the LLNL simulation code COG. The object modeled in the simulations was devised by James Hall of LLNL and is a simulation of a "Terrorist's Overnight Bag" [11], a small overnight bag filled with various materials. The bag has a thin aluminum shell (~ 40 x 30 x 10 cm^3) with a wood handle, thick cloth covering and steel fittings. Among the "innocent items" there is a newspaper, a travel umbrella, a bag of sugar (~ 100 g), a paperback book, a pen and pencil set, a small camera, a flat paper notebook and a selection of cotton, wool and nylon clothing items. The less innocent items are a 4" switchblade knife, cocaine-HCl (~ 100 g), a 300 g block of plastic explosive (50/50 wt.% mix of RDX and PETN) and an automatic pistol with extra ammunition clip,. The bag is heavily loaded with an average density of ~0.5 g/cm^3. Figure 12 gives the simulated neutron image for neutrons produced at 0° (left) and a 140 keV X-ray image typical of x-ray baggage scanners (right).

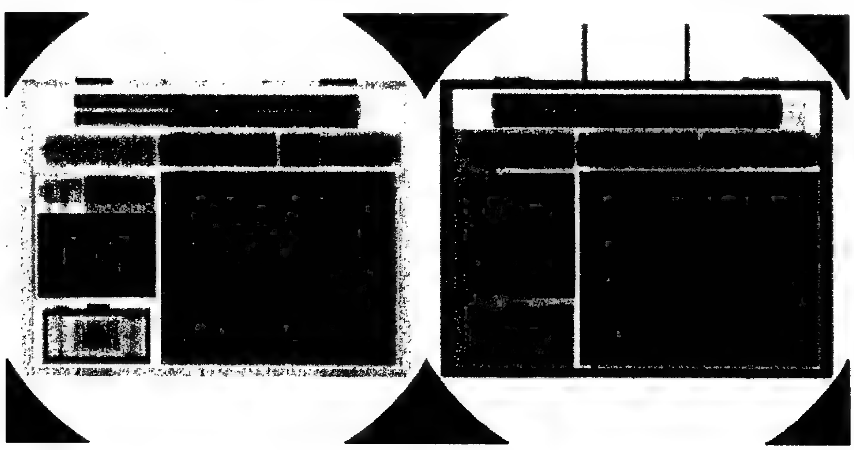

Figure 12. Fast neutron radiograph at 0° (left) and X-ray radiograph (right).

As might be expected neither method tells the book from the plastic explosive, or the sugar bag from the drug bag. We then simulated a spectrum characteristic of the angular dependence of the DD reaction. Ten angular ranges were generated and the data fitted to carbon, hydrogen, oxygen and nitrogen, with remaining materials being considered as "other". From this, both the elemental composition of items as well as their shapes can be determined which makes it possible to distinguish between organic materials of similar density and to separate the materials (Figure 13). Using the data in Figure 3, plastic explosive can be identified by its high nitrogen and oxygen content and low hydrogen and carbon content. The cocaine looks different from sugar in that the drug has about equal amounts of hydrogen and carbon

but very little oxygen. The bright bar overlapping the drug bag in the carbon image is the polystyrene handle of an umbrella. The pistol, knife blade and the battery are visible in the "other" picture. A glass lens in the camera is also very clear in the oxygen picture. Two aluminum buckles can be seen on the top in the hydrogen picture. As we have mentioned, the calculation splits aluminum content into hydrogen and "other" results.

5. CONCLUSIONS

Neutron resonance radiography can fill a specific need in the detection of contraband. Table 1 shows a comparison of some of the properties of NRR as compared to other techniques. Neutron resonance radiography provides a unique method for obtaining both elemental composition of dense objects under inspection as well as high resolution (~ mm) imaging. The spatial resolution is somewhat worse than x-ray systems but, unlike x-ray systems, elemental composition and density are measured. The limits on resolution are established mostly by the size of the beam and the resolution of the detector. The most important aspect of this technique, the determination of elemental composition provides an extremely powerful method for identification of threat materials, which more than compensates for spatial resolution. A cargo inspection system could relax the system spatial resolution requirements as well. As we have mentioned, the beam size is determined by limitations in the power handling of conventional windowed gas targets; the use of windowless targets, while somewhat more complex can be used to obtain mm resolution images. New developments in imaging detectors may enable spatial resolution comparable to x-rays and, in principle, the technique can be expanded to tomographic imaging as well. Another possible implementation method would be to use an NRR system in conjunction with an x-ray CT system, using NRR for clearing false alarms.

A critical problem inherent in this technique is the use of accelerator-based technology. To date, no accelerator-based systems have been deployed in airports whereas thousands of x-ray systems are in use. As a result, there has not been the same level of development in neutron or any other nuclear technique as in the CT systems now in use. Issues of shielding, public perception and the ability to integrate accelerators into the airport environment remain significant when compared to more conventional technologies. Table 1 lists some of the properties of various systems as compared to NRR.

Method	Element Identification	Spatial Resolution	COTS Sources	Trucks/Cargo Inspection
NRR	YES	3- 5 mm	YES	YES
PFNA	YES	5 cm	NO	YES
X-ray	NO	1 cm	YES	YES
Backscatter	Low Z only near surface	1 cm	YES	Near surface only
Tomography	NO	3 mm	YES	NO

Table 1. Some representative properties of existing technologies.

The issue of deployment depends on the ability to effectively shield the system in an environment typical of most airports. Simple shielding methods appear practical for the neutron intensities used in this system and dose rates are within current regulatory limits. The shielding requirements are directly related the efficient use of neutrons through a combination of geometric design and efficient imaging detectors. Improvements in detector efficiency directly reduces the shielding required for a given level of imaging performance. Details of these calculations can be found in [7] and [9].

ACKNOWLEDGEMENTS

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Makky of the FAA and James Petrousky and Dr. Albert Brandenstein of the Office of National Drug Control Policy encouraged and supported this work.

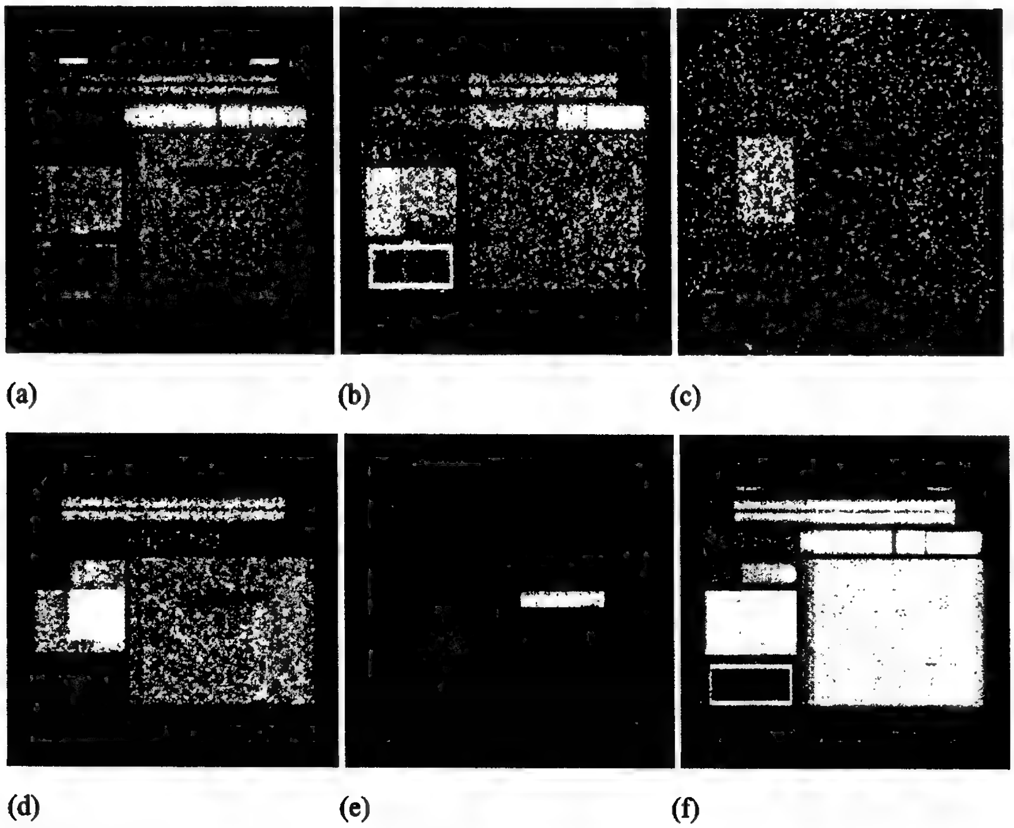

Figure 13. Calculated elemental images for different elements: (a) hydrogen; (b) carbon; (c) nitrogen; (d) oxygen; (e): other; (f) all elements.

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Portable multi-sensor for detection and identification of explosives substances

Andrey KUTNETSOV, V.G. Klophin Radium Institute, Russia

ABSTRACT

A portable version of a combined sensor for detection of explosive substances is described. The sensor is based on continuous electromagnetic ultra-high frequency waves (microwaves) and timed neutron source. Combination of both methods allows one to quickly localize hidden objects within large area and to identify them. The sensor will be capable of detecting modern explosive substances weighting 100 grams with little or no metal content within several tens of seconds.

I. INTRODUCTION

Research at Radium Institute (ISTC Project #1050) is centered on development of two methods of detection of explosive substances (ES):

- application of electromagnetic UHF waves for localization and preliminary identification of hidden objects by their dielectric properties ("microwave technique");
- irradiation of the localized object with neutrons and subsequent determination of its elemental composition by characteristic γ-rays ("nuclear technique").

The microwave technique is based on irradiation of the inspected area with low-power continuous microwave radiation and measurement of interference of the probing radiation with that scattered from objects located in the area. The on-line analysis yields both position of reflecting surfaces within the irradiated volume and dielectric properties of substances comprising the volume. The method is very fast and allows continuous scanning of large areas. It is capable of localization of suspicious objects within the area and their preliminary identification by their dielectric properties.

The main idea of the nuclear technique is to irradiate of the localized unknown object with neutrons from isotopic sources or portable neutron generator and to simultaneously measuring secondary γ-radiation induced by neutrons in the object and charged particles that accompany neutron emission from the source. The latter allows one to use "marked" neutrons and to carry out detection of secondary γ-radiation in narrow (nanosecond) time intervals, thus considerably

[1] This work is supported by the International Science and Technology Center, ISTC Project #1050.

reducing the identification time. By using position-sensitive detector of accompanying alpha particles one can obtain a 3D elemental image of the inspected volume and identify explosives hidden inside large volumes of metallic, organic or other material.

II. MICROWAVE SENSOR

To determine dielectric properties of hidden substances an automated experimental installation was created. The range of frequencies of the microwave radiation in this installation (5 – 25 GHz) were chosen to satisfy two conditions: high spatial resolution (1,2 – 6 cm) and acceptable penetrating ability of radiation in damp media. Unlike pulsed radars, in our method the inspected area is continuously irradiated by a probing wave with changing frequency.

The main advantages of such systems compared to pulsed radars are:

- It is easy to provide a wide range of frequencies equivalent to pulse length $\Delta t \sim 0.1$ ns, hence spatial resolution $\Delta L \sim c\Delta t \sim 3$ cm.
- Possibility of off-line correction of amplitude and frequency characteristics of the emitter and the receiver.
- Well-defined frequency boundaries of the signal, outside which it has zero energy.
- Less strict requirements to the quality of emitter and receiver, and to their decoupling.

It was experimentally shown that metals and dielectrics, including explosives, can be efficiently localized with continuous ultra-high frequency radiation. This technique allows one to carry out pre-identification of the hidden object. Procedure was developed to identify dielectric objects, including explosives in non-metallic cases. This procedure was applied to cases of high attenuation and dispersion (wet sand). A more detailed description of the technique was given in [1].

The method will be further developed to achieve good results for media with higher humidity. This will be done by introducing a reference channel, increasing the sensitivity of the receiver, optimizing the antennae system, introducing 2-dimensional correlation and statistical analysis, and using a wider range of samples and ES imitators and more precise models.

At present a portable version of the microwave sensor is under construction (see Figure 1).

It will have the following characteristics:

- continuous microwaves in frequency range 2 – 8 GHz;
- number of frequency points per range – not less than 50;
- time of analysis of one scanning cycle – less than 0.1 second;
- the power of radiation – about 10 mW;
- sensitivity – 120 dB/W;

- dynamical sensitivity range – 40 dB with possibility of changing the range depending on the level of the reflected signal;
- spatial resolution: transversal – 4 cm, longitudinal – 3 cm;
- penetrating ability of radiation in medium with humidity 20% by weight – up to 10 cm; with humidity 5% by weight – up to 20 cm;
- time of continuous work without battery recharging – 8 hours.

The sensor can be easily operated by one operator, and is completely safe for people, film, etc.

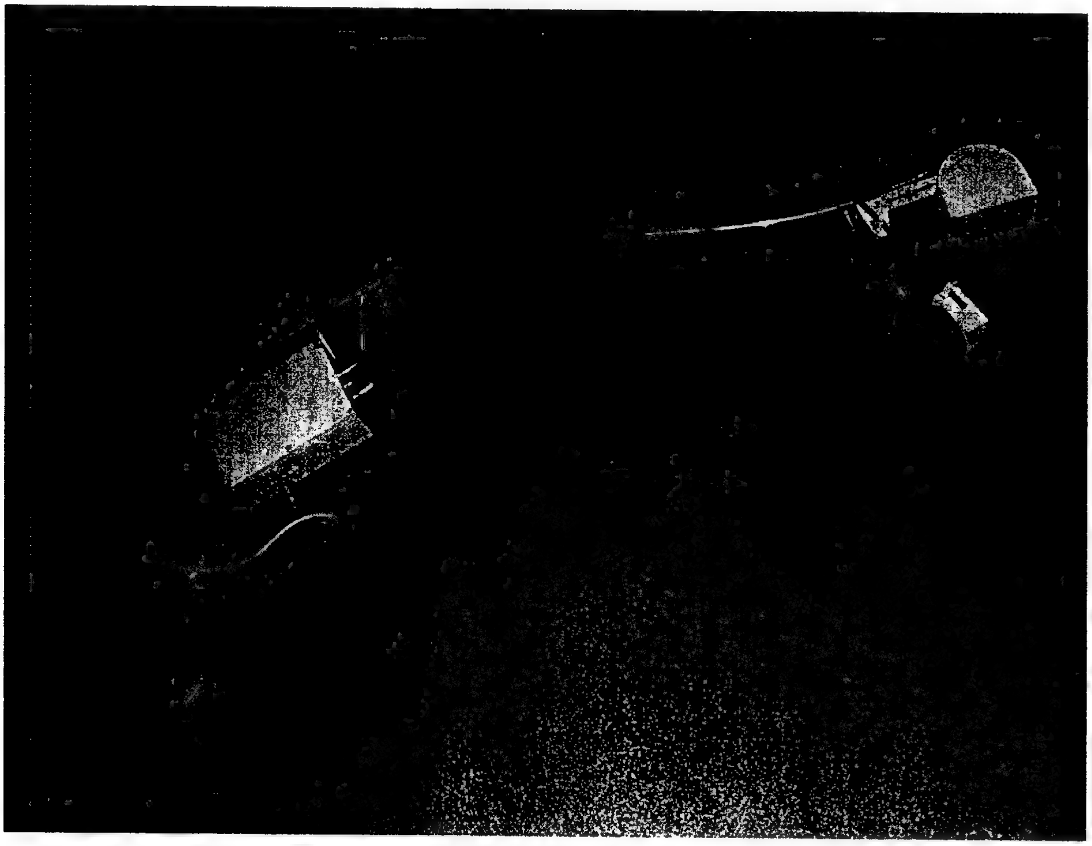


Figure 1. View of the portable microwave sensor, which can quickly localize hidden metallic and dielectric objects.

III. NUCLEAR SENSOR

A. Existing Device Based on Timed Isotopic Neutron Source

The existing prototype of nuclear sensor is based on timed isotopic neutron source (^{252}Cf, 4×10^6 neutrons per second) enclosed in a miniature ionization chamber [2-6]. Gamma rays induced in the inspected object by neutrons from the source are detected by NaI(Tl) detector in coincidence (10ns-wide time window) and anti-coincidence with fission fragments of ^{252}Cf (see photos at Figure 2). The coincidence spectrum contains γ-rays from inelastic scattering of fast neutrons on nuclei of the object, while the anti-coincidence spectrum corresponds to capture of thermal neutrons. In the coincidence mode the background is suppressed by more that an order of magnitude, since only a small fraction of the background γ-rays fit into the 10 ns-wide measurement window.

The measured spectra of secondary γ-radiation allow one to determine relative concentration of the main chemical elements (carbon, oxygen, nitrogen, hydrogen and others) in the inspected object. Explosives and other dangerous substances are characterized by specific ratio of concentrations of chemical elements, that allows identifying them in the presence of other substances and household goods.

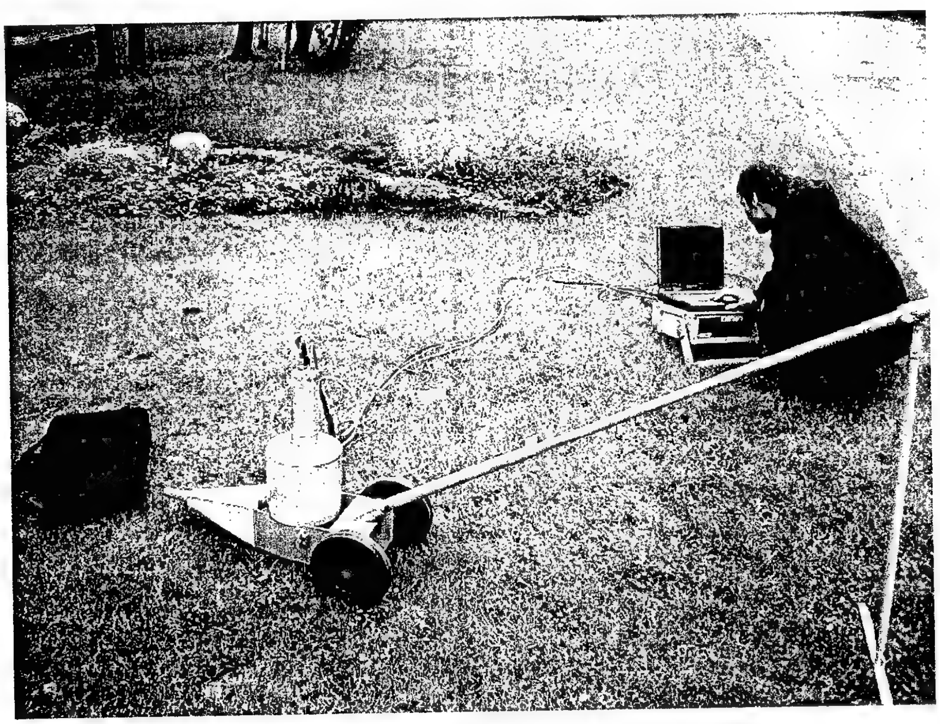


Figure 2. Existing prototype of the mobile device for detection of explosive substances during the field test at Radium Institute.

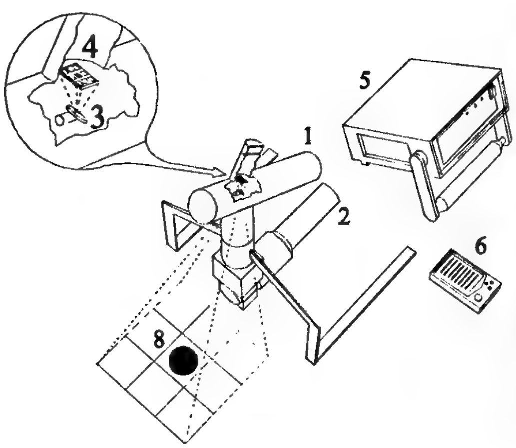
The prototype is serviced by a specialized block of electronics which contains battery power supplies, fast analogue electronics, ADCs and a programmable processor, which performs data collection, storage and transfer to the external PC for analysis.

The prototype has been tested in laboratory using phantoms of trinitrotoluene (TNT) and samples of common materials: iron, wood, water, etc. Samples were placed into media with different humidity (up to 20% by weight) at depths up to 5 cm.

It has been established that the current prototype can distinguish between TNT and non-explosive substances weighting not less than 400 grams in 5 minutes. At present tests are under way to try detection of various explosive substances hidden in soil, walls, hand luggage. However use of an isotopic neutron source limits application of the existing device.

B. Portable Sensor with Timed Neutron Generator

At present Radium Institute and All-Russia Research Institute of Automatics are working on the portable device, in which a portable neutron generator with built-in system of detection of accompanying particles is used as a source of neutrons [7]. The neutron generator is a small accelerator, which does not create any radiation when it is switched off. The sectioned detector of accompanying α-particles allows one to determine the location of the hidden object within the inspected area. The portable device consists of the neutron generator, γ-detector, detector shielding, block of electronics with battery power supply and is controlled from a pocket computer (see drawing on Figure 3).



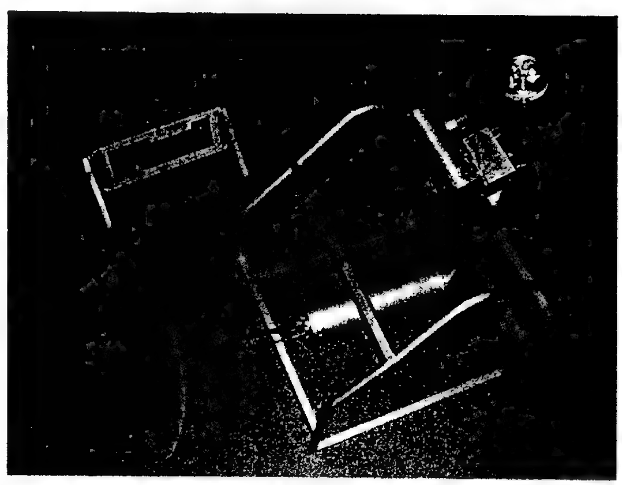


Figure 3. Left: portable device for detection of explosive substances. 1 - neutron generator with built-in sectioned detector of accompanying α-particles, 2 – γ-ray detector, 3 - target, 4 - segmented detector of the accompanying particles, 5 - specialized block of electronics, 6 - pocket computer (control panel), 7 – the inspected area, 8 - hidden object. Right: view of the existing prototype.

Its expected characteristic are:

1. Detection and identification of explosives weighting 100 grams in 10 seconds.
2. Simultaneously surveyed area 30 cm × 30 см (12 in × 12 in) up to depth 20 cm with position resolution 10 cm × 10 cm × 10 cm.
3. Total weight – not more than 30 kg.
4. Ability to work in the range of temperatures -25° – +50°C, independent power supply (8 hours of continuous work without recharging or replacing of batteries).

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Practical aspects of using explosive detection techniques

Israel HIRSCH, Aphelion Ltd., Israel

Aphelion Ltd.

Practical Aspects Of Explosive Detection Techniques

By

Israel Hirsch, Ph.D.

Bled Lake – Slovenia, 2-4 June 2003

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Presentation's Road Map

- ❑ Crystal Grating Technology
  - The wave meter
  - Spectrometer based on wave meter
- ❑ Crystal Grating Technique for Explosives Detection.
  - The "FRED" project
  - Other practical applications.
- ❑ Thoughts on Dual/Multi Energy X-Rays Backscatter Imaging

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Wavelength Measurement

- Prism
- **Grating - lens**
- Etalon/Fabry-Perot
- Michelson (Fourier Spectroscopy)
- Birefringent filter

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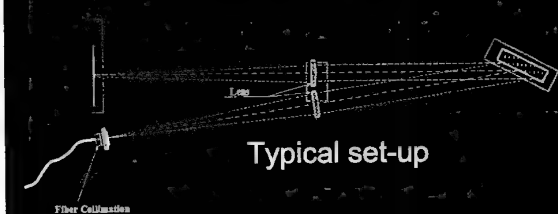
Grating - lens



Typical set-up

Step 1: Transformation of the optical wavelength to angular information
Step 2: Transformation of angular information into optical position
Step 3 : Extraction of wavelength from the space dependant signal

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Grating – Lens Equations

- ❑ Space dependant
- ❑ Grating equation
  $\sin\beta = m\lambda/d - \sin\alpha$
- ❑ Space based detection
  $x = f(\beta - \beta_0)$

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Grating – Lens Fundamentals

❑ Diffraction limit and aberrations	Yes
❑ Detector pixel size limitation	Yes
❑ Use of non collimated light	No
❑ Grating resolution limit	Yes
❑ The read out is limited by the output rate of the sensor divided by the number of pixels	

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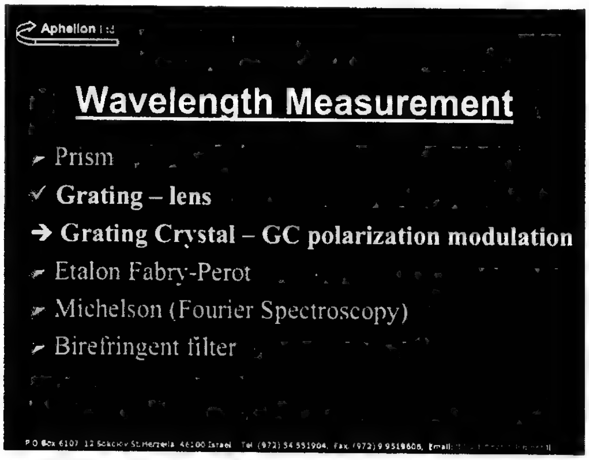
Aphelion Ltd
Wavelength Measurement
Prism
Grating – lens
Grating Crystal – GC polarization modulation
Etalon Fabry-Perot
Michelson (Fourier Spectroscopy)
Birefringent filter
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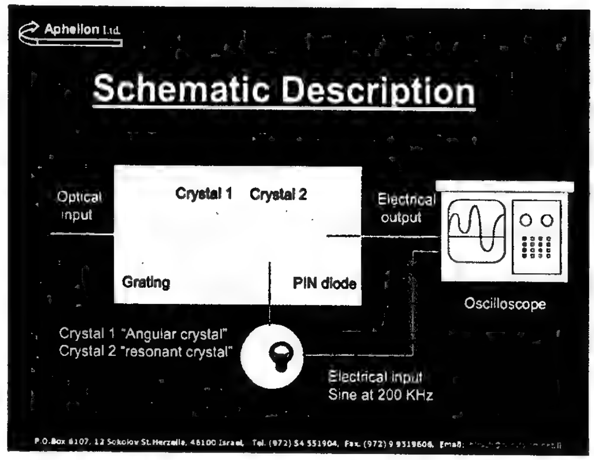
Aphelion Ltd
Schematic Description
Optical input
Crystal 1
Crystal 2
Electrical output
Grating
PIN diode
Oscilloscope
Crystal 1 "Angular crystal"
Crystal 2 "resonant crystal"
Electrical input
Sine at 200 KHz
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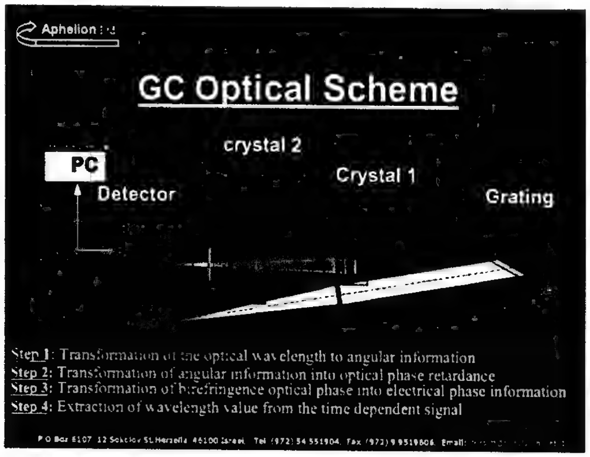
Aphelion Ltd
GC Optical Scheme
PC
crystal 2
Crystal 1
Detector
Grating
Step 1: Transformation of the optical wavelength to angular information
Step 2: Transformation of angular information into optical phase retardance
Step 3: Transformation of birefringence optical phase into electrical phase information
Step 4: Extraction of wavelength value from the time dependent signal
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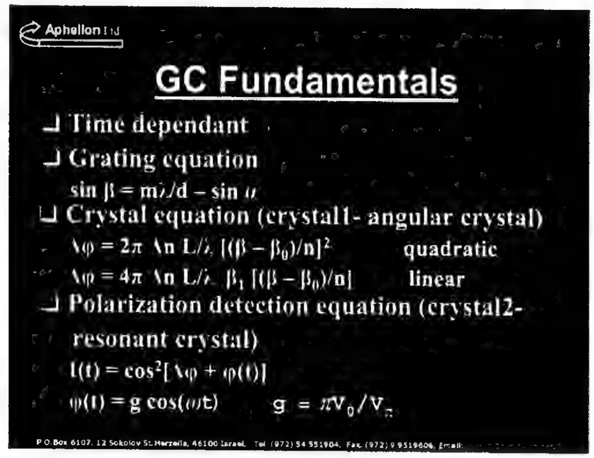
Aphelion Ltd
GC Fundamentals
Time dependant
Grating equation
$\sin\beta = m\lambda/d - \sin\alpha$
Crystal equation (crystal1- angular crystal)
$\Delta\varphi = 2\pi\,\Delta n\,L/\lambda\,[(\beta-\beta_0)/n]^2$ quadratic
$\Delta\varphi = 4\pi\,\Delta n\,L/\lambda\,\beta_1\,[(\beta-\beta_0)/n]$ linear
Polarization detection equation (crystal2- resonant crystal)
$I(t) = \cos^2[\Delta\varphi + \varphi(t)]$
$\varphi(t) = g\cos(\omega t)$ $g = \pi V_0/V_\pi$
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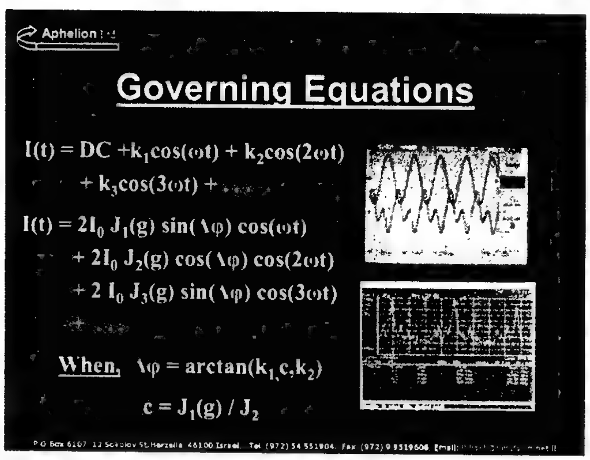
Aphelion Ltd
Governing Equations
$I(t) = DC + k_1\cos(\omega t) + k_2\cos(2\omega t) + k_3\cos(3\omega t) + \ldots$
$I(t) = 2I_0 J_1(g)\sin(\Delta\varphi)\cos(\omega t) + 2I_0 J_2(g)\cos(\Delta\varphi)\cos(2\omega t) + 2I_0 J_3(g)\sin(\Delta\varphi)\cos(3\omega t)$
When, $\Delta\varphi = \arctan(k_1 c, k_2)$
$c = J_1(g)/J_2$
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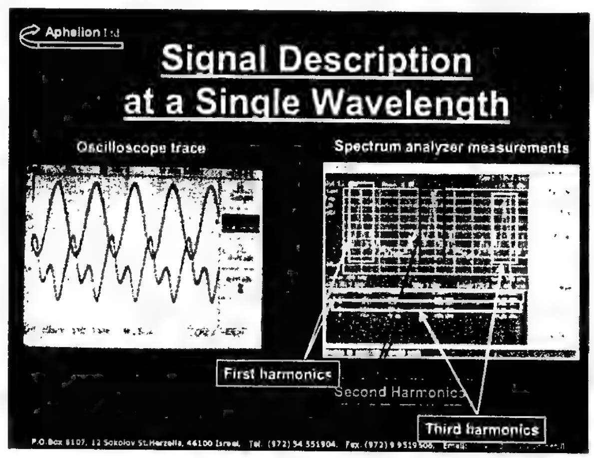
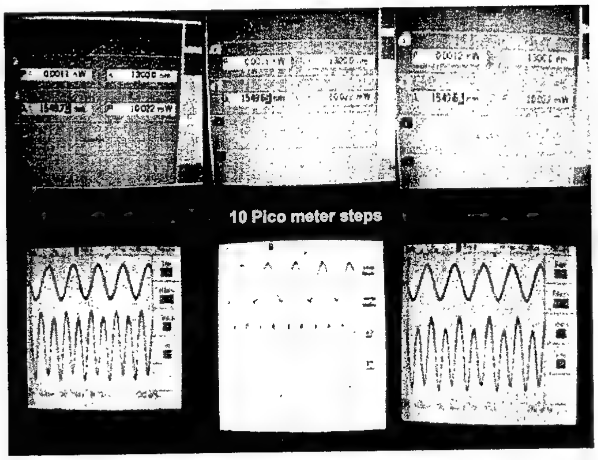
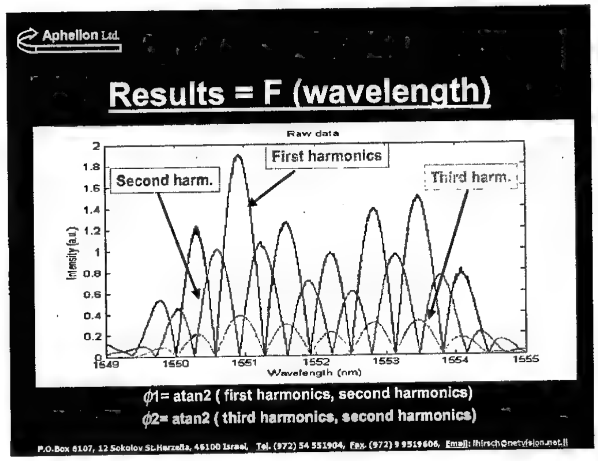

Aphelion Ltd
Signal Description
at a Single Wavelength
Oscilloscope trace
Spectrum analyzer measurements
First harmonics
Second Harmonics
Third harmonics
P.O.Box 6107, 12 Sokolov St.Herzelia, 46100 Israel. Tel. (972) 54 551904. Fax (972) 9 9519606. Email:


10 Pico meter steps


Aphelion Ltd.
Results = F (wavelength)
Raw data
First harmonics
Second harm.
Third harm.
Intensity (a.u.)
Wavelength (nm)
ϕ1= atan2 (first harmonics, second harmonics)
ϕ2= atan2 (third harmonics, second harmonics)
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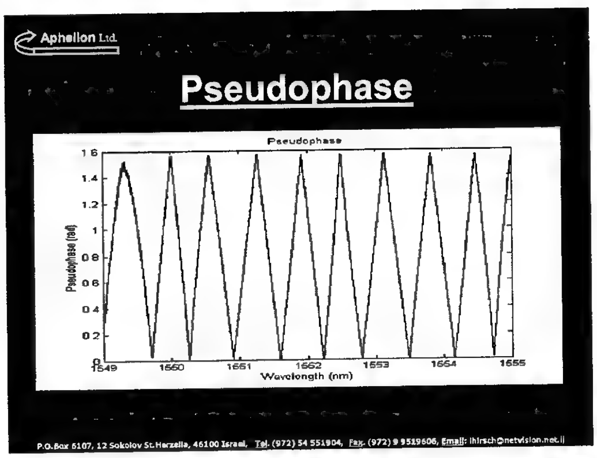
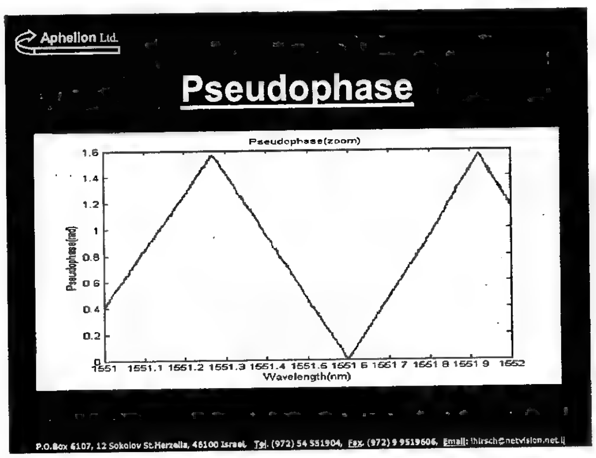

Aphelion Ltd.
Pseudophase
Pseudophase
Pseudophase (rad)
Wavelength (nm)
P.O.Box 6107, 12 Sokolov St.Herzelia, 46100 Israel, Tel. (972) 54 551904, Fax. (972) 9 9519606, Email: ihirsch@netvision.net.il


Aphelion Ltd.
Pseudophase
Pseudophase(zoom)
Pseudophase(rad)
Wavelength(nm)
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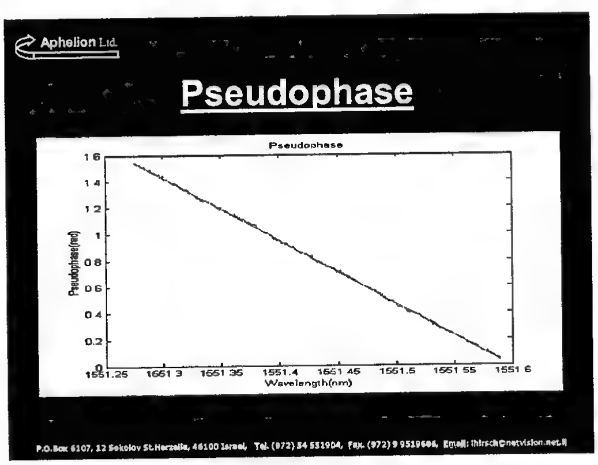
Aphelion Ltd.
Pseudophase
Pseudophase
Pseudophase(rad)
Wavelength(nm)
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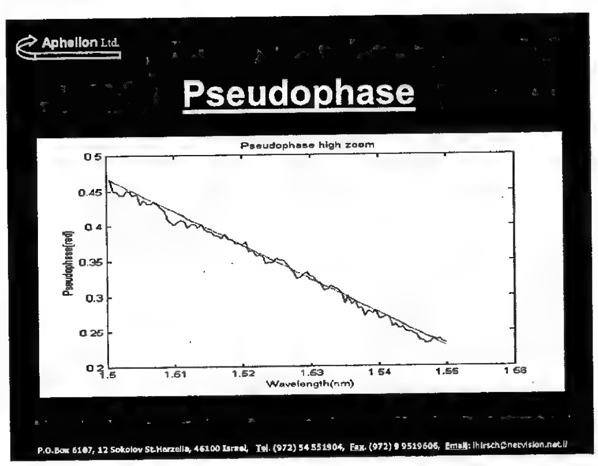
Aphelion Ltd.
Pseudophase
Pseudophase high zoom
Pseudophase(rad)
Wavelength(nm)
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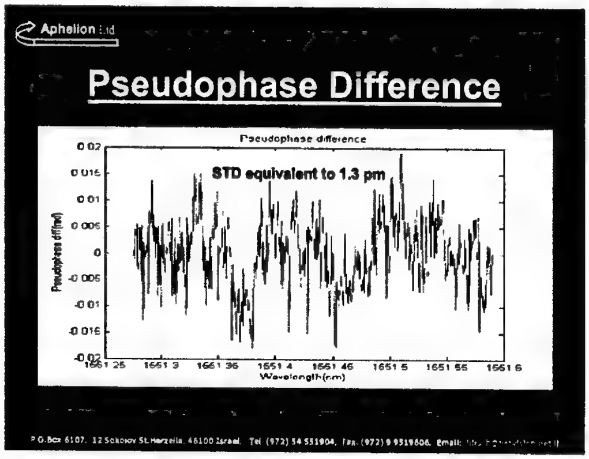

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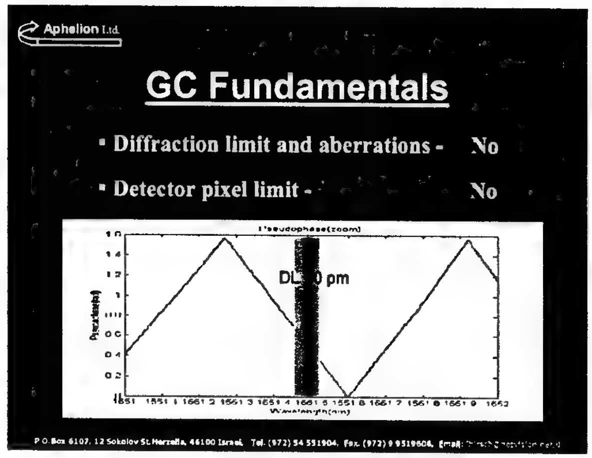
Pseudophase Difference
Pseudophase difference
STD equivalent to 1.3 pm
Wavelength(nm)



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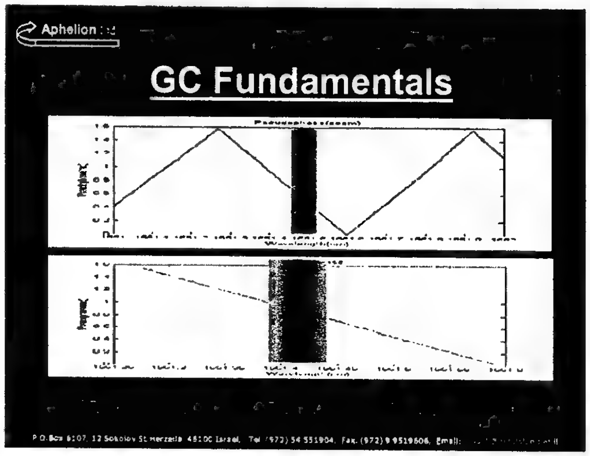
GC Fundamentals
▪ Diffraction limit and aberrations - No
▪ Detector pixel limit - No
Pseudophase(zoom)



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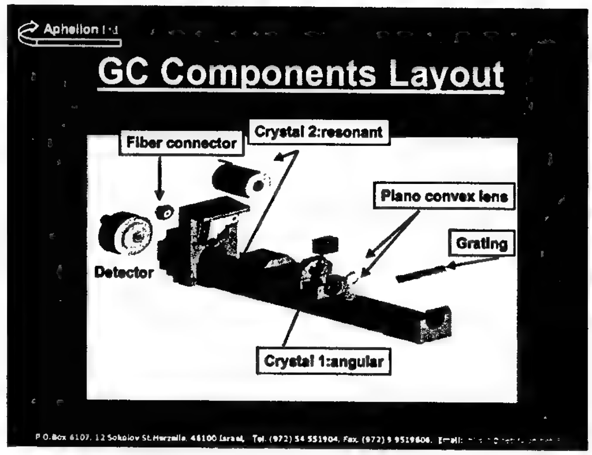
GC Fundamentals



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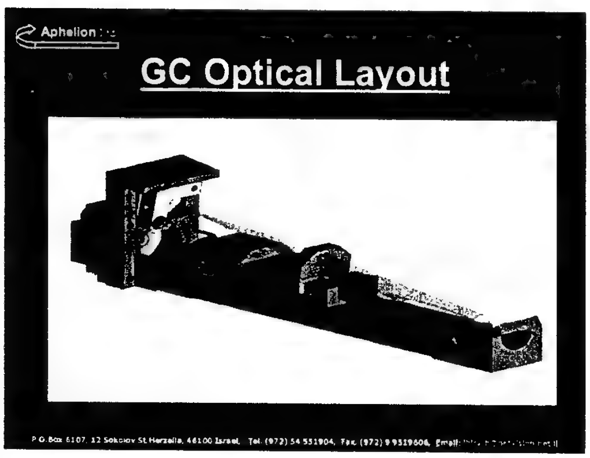
GC Components Layout
Fiber connector
Crystal 2:resonant
Plano convex lens
Grating
Detector
Crystal 1:angular



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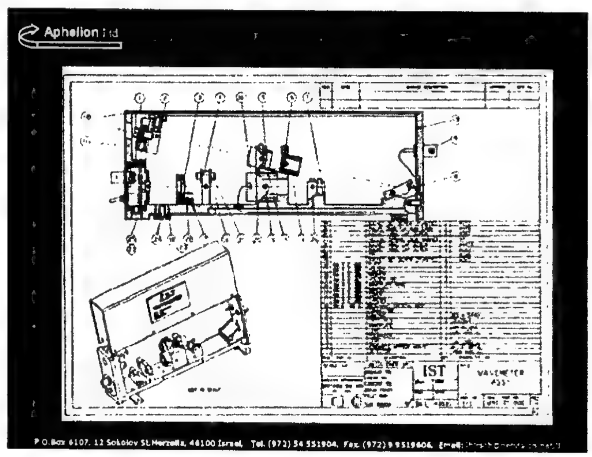
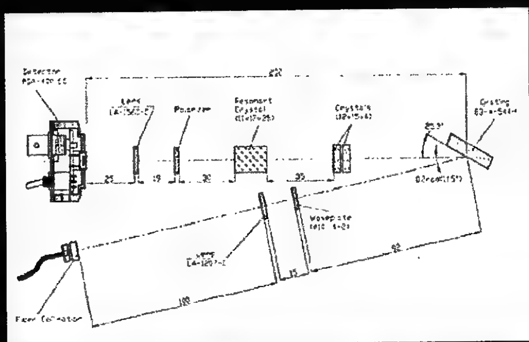
GC Optical Layout



Aphelion Ltd
IST

Aphelion Ltd.



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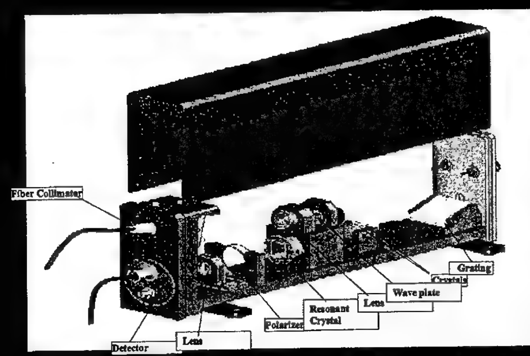

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Grating - Crystal fundamentals

- Diffraction limit and aberrations No
- Detector pixel limit - No
- Parallel light - No
- Grating resolution limit - No
- Time response limited by the Signal to Noise ratio and PIN diode electrical bandwidth.

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GC's - Technological Capacity

- Capability of measuring wavelength of light sources with high accuracy and high speed.
- Capability of resolving two adjacent wave-length with order of magnitude differences intensities.
- Capability of measuring low level light intensity.
- Capability of measuring and analyzing continuous spectra

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GC's - Advantages

- ✓ High precision, pm to sub pm resolution
- ✓ Multiple spectral line using single detector.
- ✓ Response time in the µsec. range: transient effect record
- ✓ Highly sensitive, High optical efficiency
- ✓ Measurements precision is independent of input beam collimation.
- ✓ No need for warm up time.
- ✓ Low cost and size

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GC's Precision Limitations

- Error in measuring phase between two electrical signals.
- Engineering limitation in the accuracy of crystal dimensions.

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GC's physical features

- Micro system available from UV to FIR.
- Off the shelves components.
- Low cost Bill Of Material (BOM).
- Loose mechanical tolerances.
- Small volume.
- Hand held.
- No moving parts.

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Presentation's Road Map

- ☐ Crystal Grating Technology
  - ✓ The wave meter
  - ▪ Spectrometer based on the wave meter
- ☐ Crystal Grating Technique for Explosives Detection.
  - ▪ The "FRED" project
  - ▪ Other practical applications.
- ☐ Thoughts on Dual/Multi Energy X-Rays Backscatter Imaging.

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Prof. Dan Neuhauser originated the idea of

Filter Diagonalization Method (FDM)

High resolution method for spectral analysis of multidimensional time signal

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Advantages of FDM

- Small Linear algebra problem: diagonalizing some data matrices, with dimension << # of signal terms. For example, if there are 1000 different sin-terms contributing to the signal, still a 2*2 matrix can be used in each spectral range.
- Fast (~FFT), efficient, stable, handles overlap.
- No assumptions about the number of peaks. (No need to even know how many peaks are there!)
- Local spectral analysis (each spectral range handled separately).

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Advantages of FDM (cont.)

- Direct fit of multidimensional signal.
- Extends FFT.
- Bridges FFT and other approaches.
- Bypasses $(\Delta w)\, T_{max} \geq 1$

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Application of FDM

to

Crystal Grating

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Crystal Grating Essence

- Wavelength → Grating Angle → Final polarization

$I(t)=\cos^2[\Delta\varphi + g\cos(\omega t)]$

where: $\Delta\varphi = 4\pi\, \Delta n\, L/\lambda\ \beta_1\, [(\beta-\beta_0)/n]$

$$\boxed{M(out)=I(in)*(1+\cos(\mathbf{x},\lambda))}$$

M: output measurement

λ: Wavelength

x : parameter; depends on: Crystal length, Grating Angle

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Continuous spectrum: General Spectra

$M(x) = \text{Integral } I(\lambda) \cos(x\lambda)\ d\lambda$

$I(\lambda)$: relative intensity

Key to extract $I(\lambda)$: Vary the parameter x

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Spectrum extraction:

$I(f) \sim \text{Integral } M(x) \cos(x\,\lambda)\ dx$

Vary x continuously; one or combination of:

i) Wedge (varying crystal length).
ii) (Alternate: Change angle)
iii) Voltage on resonant crystal

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Wedge:

$I(\lambda) \sim \text{Integral } M(x) \cos(x\,\lambda)\ dx$

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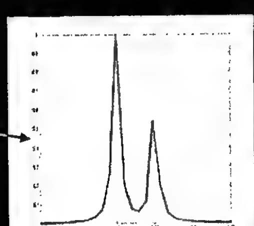
Example: Two neighboring lines.

$M(x) = \text{Integral } I(\lambda) \cos(x\,\lambda)\ d\lambda$

Need to invert relation.

Desired spectrum:



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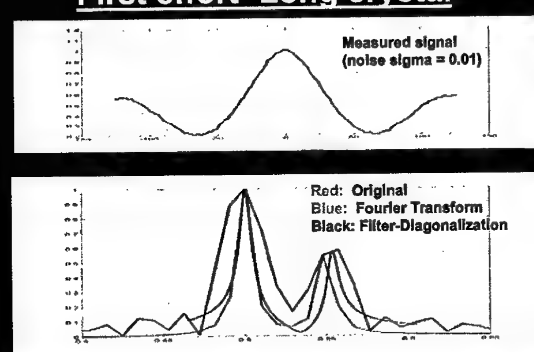
First effort- Long crystal



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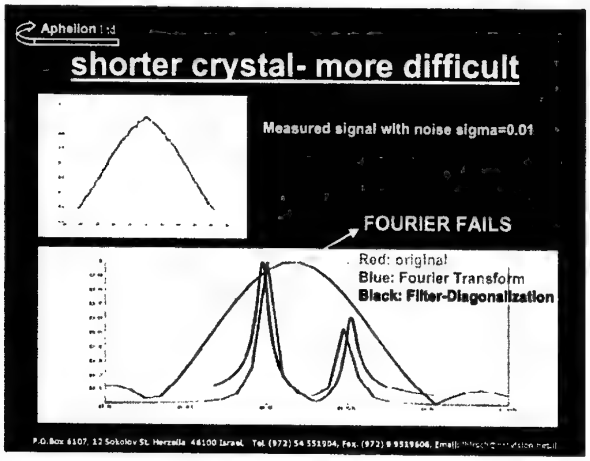
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shorter crystal- more difficult
Measured signal with noise sigma=0.01
FOURIER FAILS
Red: original
Blue: Fourier Transform
Black: Filter-Diagonalization
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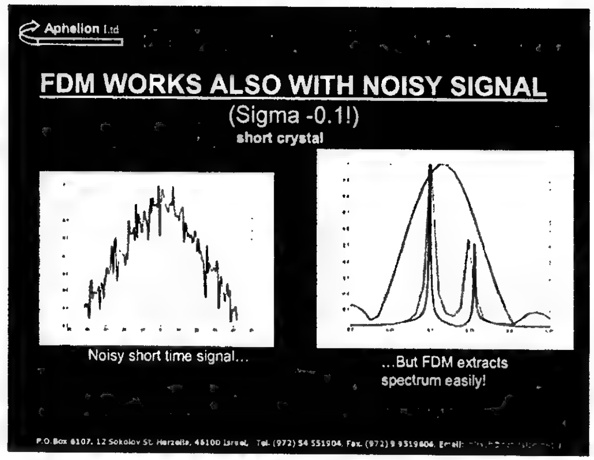
Aphelion Ltd
FDM WORKS ALSO WITH NOISY SIGNAL
(Sigma -0.1!)
short crystal
Noisy short time signal...
...But FDM extracts spectrum easily!
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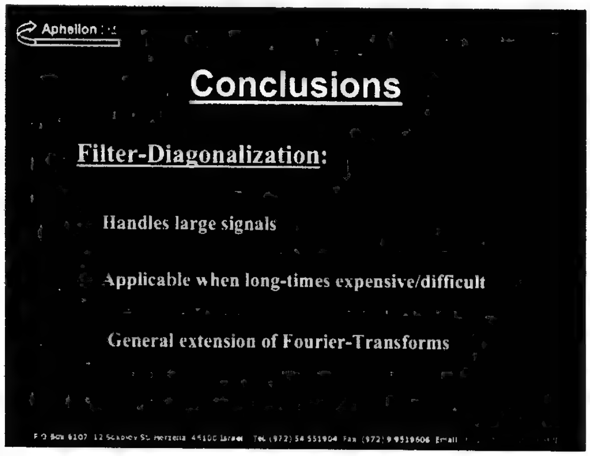
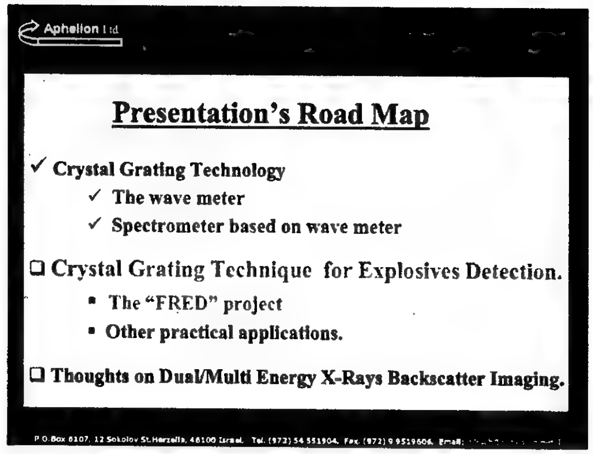

Aphelion Ltd
Conclusions
Filter-Diagonalization:
Handles large signals
Applicable when long-times expensive/difficult
General extension of Fourier-Transforms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Presentation's Road Map
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▪ The "FRED" project
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❑ Thoughts on Dual/Multi Energy X-Rays Backscatter Imaging.
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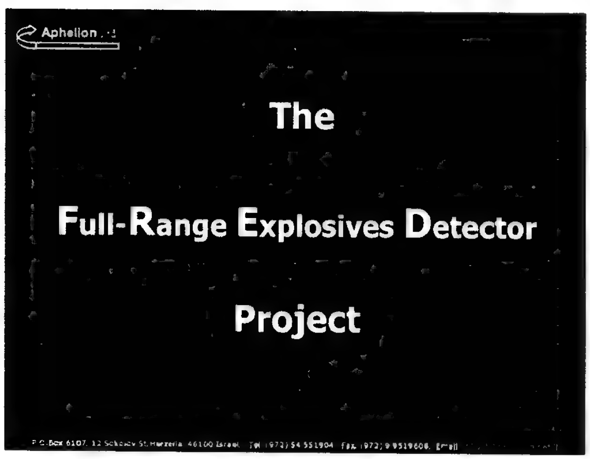
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The
Full-Range Explosives Detector
Project


Aphelion Ltd
ETK five
Explosives Testing Kit
A Portable micro-laboratory for rapid detection of explosives
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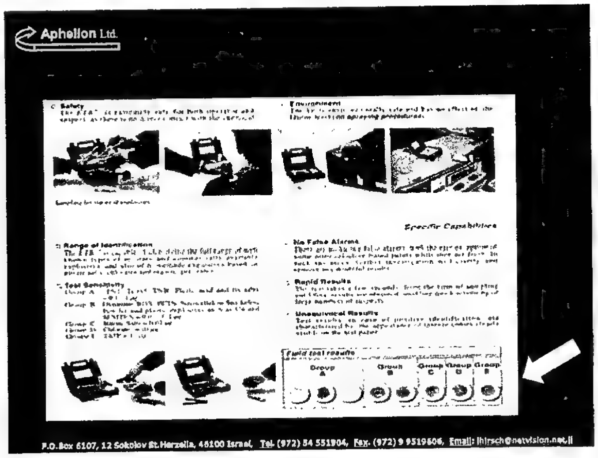
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Safety
Environment
Specific Capabilities
Range of Identification
No False Alarms
Test Sensitivity
Rapid Results
Unequivocal Results
Field test results
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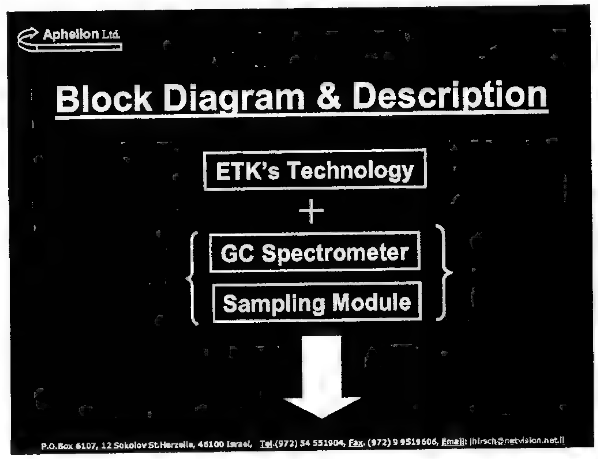
Aphelion Ltd.
Block Diagram & Description
ETK's Technology
+
GC Spectrometer
Sampling Module
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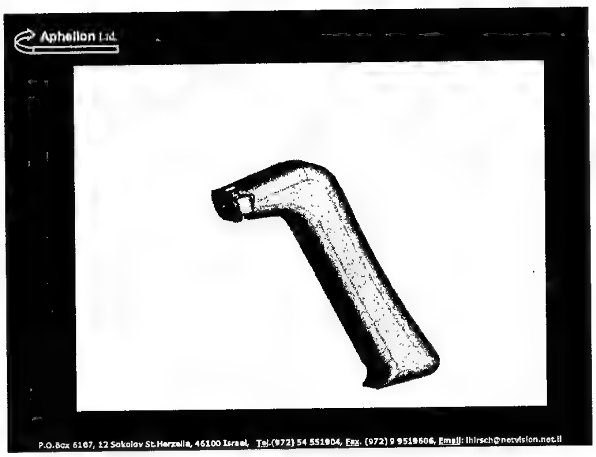
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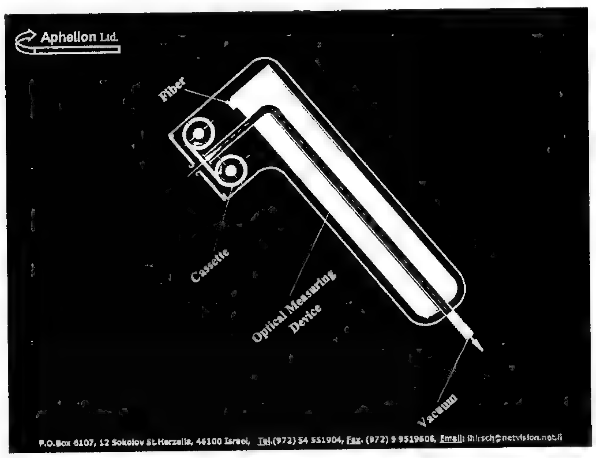
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Fiber
Cassette
Optical Measuring Device
Vacuum
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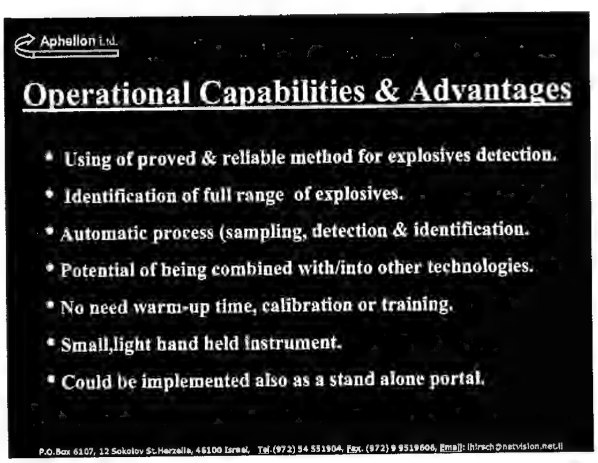
Aphelion Ltd.
Operational Capabilities & Advantages
• Using of proved & reliable method for explosives detection.
• Identification of full range of explosives.
• Automatic process (sampling, detection & identification.
• Potential of being combined with/into other technologies.
• No need warm-up time, calibration or training.
• Small,light hand held instrument.
• Could be implemented also as a stand alone portal.
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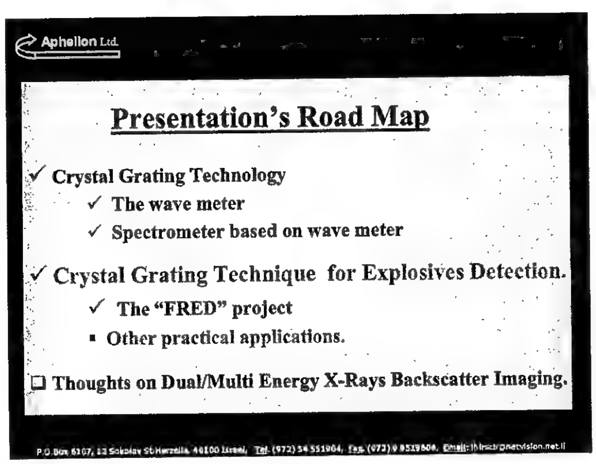
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Other Practical Applications

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CG's Possible Applications

- Security Technologies
  - Explosives detection by using reagents reactions
  - Remote sensing of explosives using Raman Spectroscopy a/o scattering.
- Communication
  - Laser wavelength monitoring.
  - Stabilizing laser wavelength.
- Industrial and laboratories
  - Materials
  - Biology
  - Chemistry

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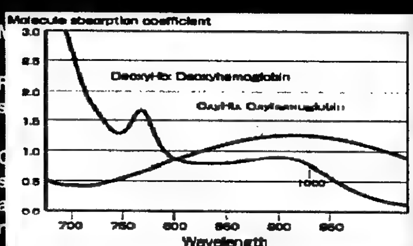
Three main possible implementations in spectroscopy



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❑ Thoughts on Dual/Multi Energy X-Rags Backscatter Imaging.

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Thoughts on

Dual/Multi-Energy X-rays Backscatter imaging

for

Detection of Buried Land Mines

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X-Ray Backscatter Imaging

By

Bruce C. Towe and Alan M. Jacobs

As Published on
IEEE Transaction on Biomedical Engineering,
Vol. BME-28, No. 9, September 1981

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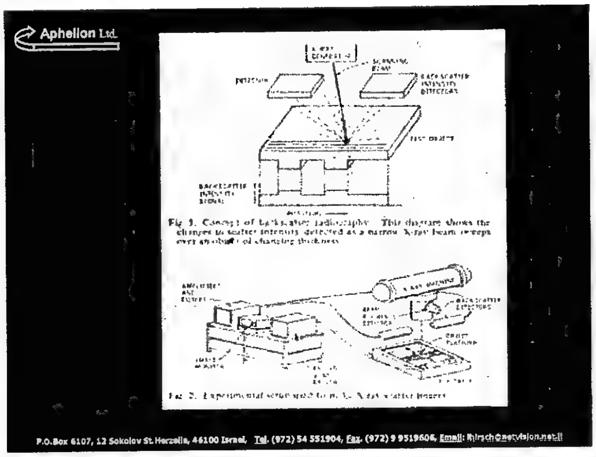
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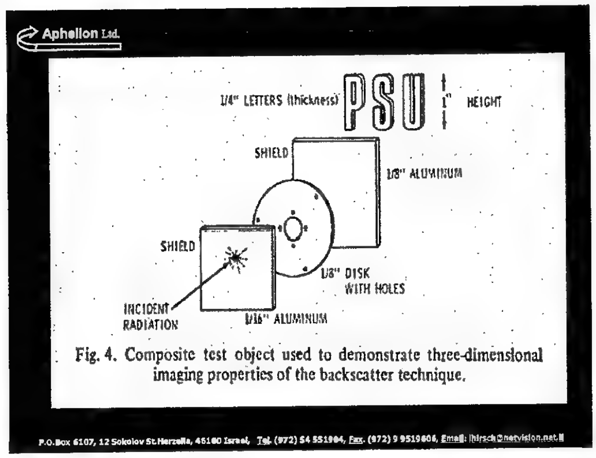
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1/4" LETTERS (thickness)
PSU
1" HEIGHT
SHIELD
1/8" ALUMINUM
SHIELD
1/8" DISK WITH HOLES
INCIDENT RADIATION
1/16" ALUMINUM
Fig. 4. Composite test object used to demonstrate three-dimensional imaging properties of the backscatter technique.
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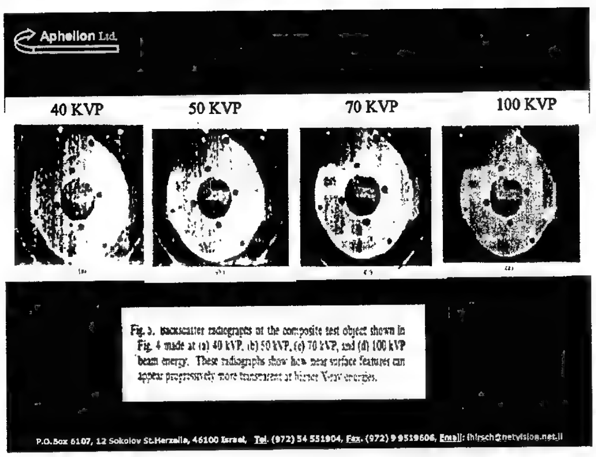
Aphelion Ltd.
40 KVP
50 KVP
70 KVP
100 KVP
Fig. 5. Backscatter radiographs of the composite test object shown in Fig. 4 made at (a) 40 kVP, (b) 50 kVP, (c) 70 kVP, and (d) 100 kVP beam energy. These radiographs show how near surface features can appear progressively more transparent at higher X-ray energies.
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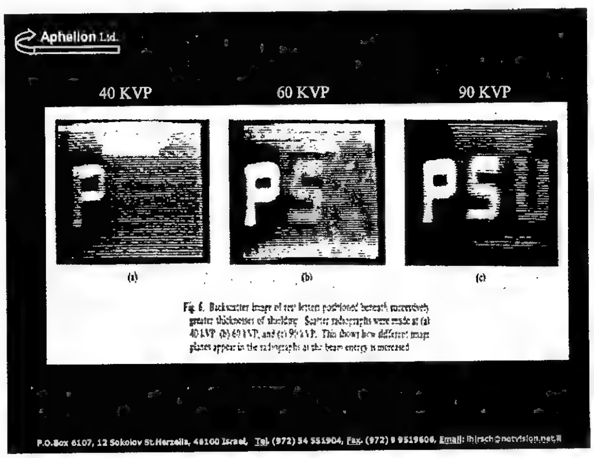
Aphelion Ltd.
40 KVP
60 KVP
90 KVP
(a)
(b)
(c)
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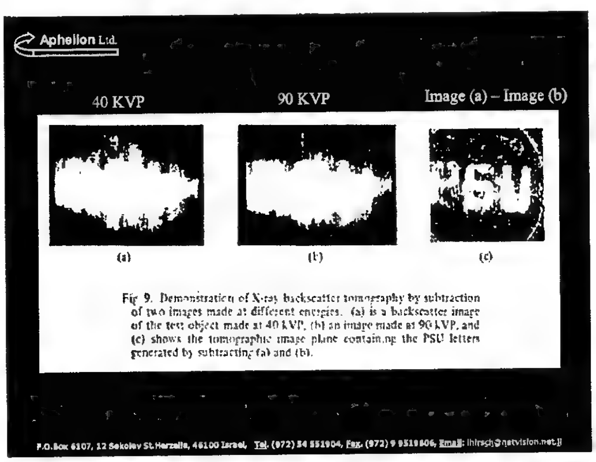
Aphelion Ltd.
40 KVP
90 KVP
Image (a) – Image (b)
(a)
(b)
(c)
Fig. 9. Demonstration of X-ray backscatter tomography by subtraction of two images made at different energies. (a) is a backscatter image of the test object made at 40 kVP, (b) an image made at 90 kVP, and (c) shows the tomographic image plane containing the PSU letters generated by subtracting (a) and (b).
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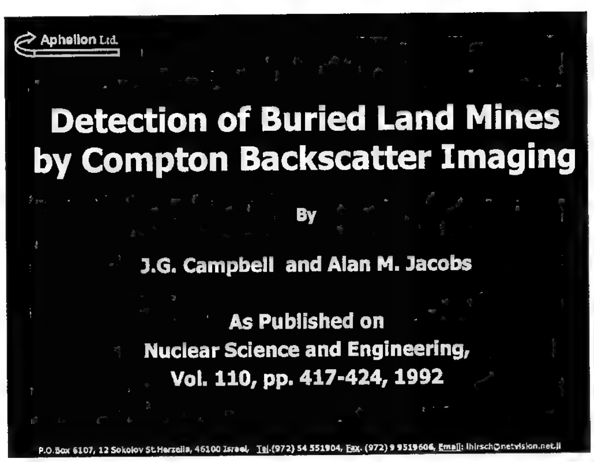
Aphelion Ltd.
Detection of Buried Land Mines by Compton Backscatter Imaging
By
J.G. Campbell and Alan M. Jacobs
As Published on
Nuclear Science and Engineering,
Vol. 110, pp. 417-424, 1992
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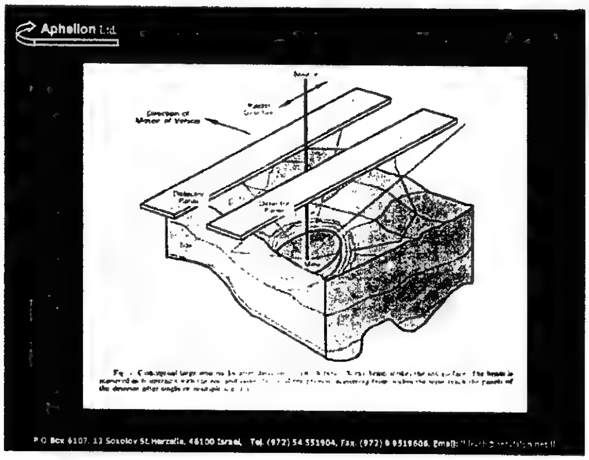


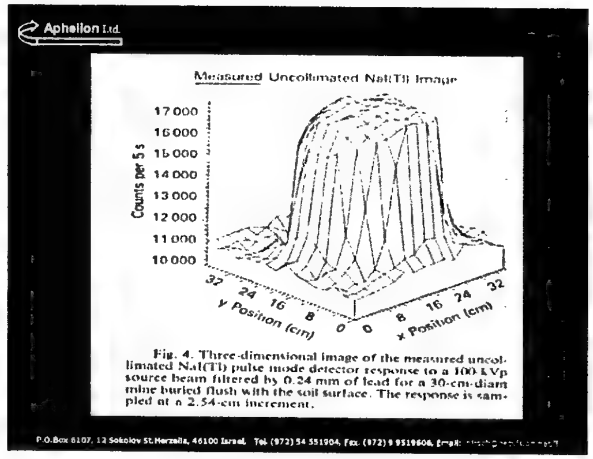


Fig. 4. Three-dimensional image of the measured uncollimated NaI(Tl) pulse mode detector response to a 100-kVp source beam filtered by 0.24 mm of lead for a 30-cm-diam mine buried flush with the soil surface. The response is sampled at a 2.54-cm increment.

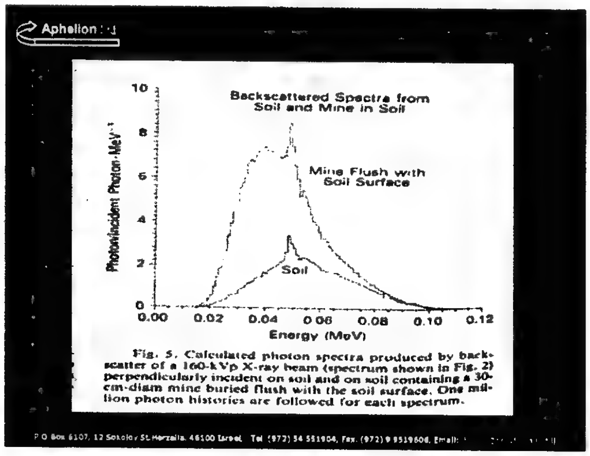
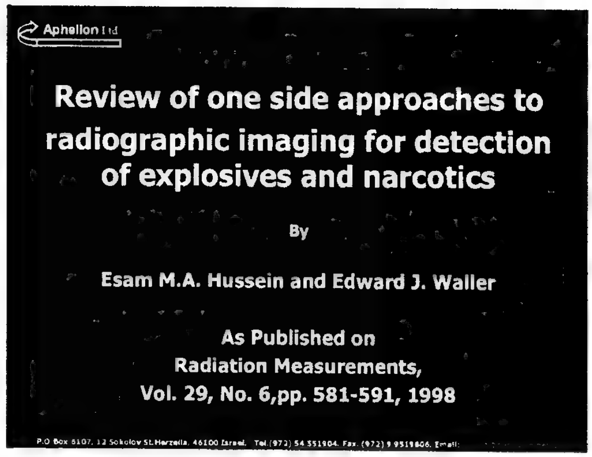
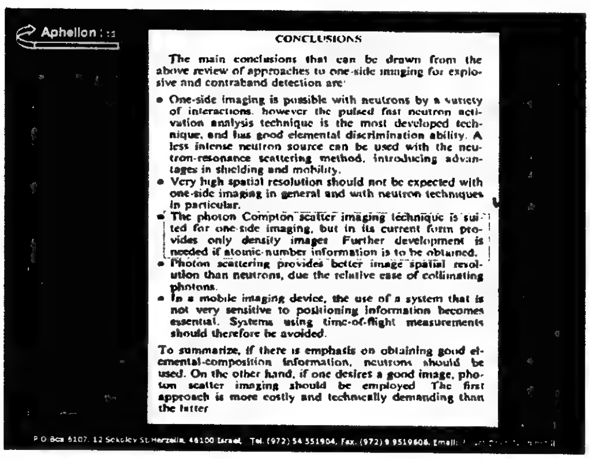


Fig. 5. Calculated photon spectra produced by backscatter of a 160-kVp X-ray beam (spectrum shown in Fig. 2) perpendicularly incident on soil and on soil containing a 30-cm-diam mine buried flush with the soil surface. One million photon histories are followed for each spectrum.



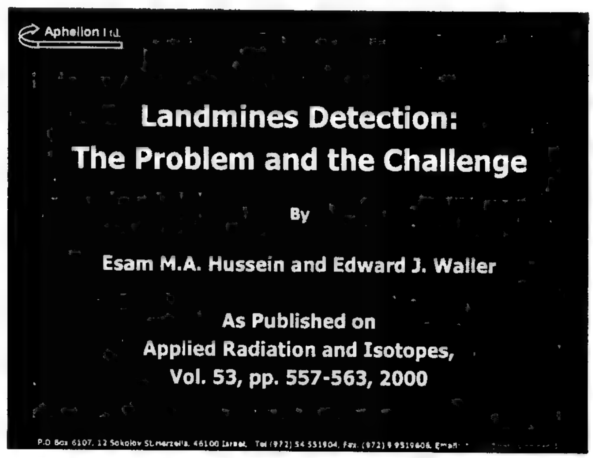


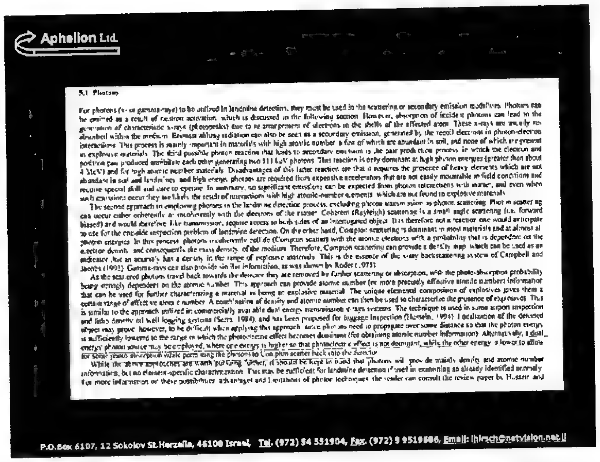
CONCLUSIONS

The main conclusions that can be drawn from the above review of approaches to one-side imaging for explosive and contraband detection are:

- One-side imaging is possible with neutrons by a variety of interactions, however the pulsed fast neutron activation analysis technique is the most developed technique, and has good elemental discrimination ability. A less intense neutron source can be used with the neutron-resonance scattering method, introducing advantages in shielding and mobility.
- Very high spatial resolution should not be expected with one-side imaging in general and with neutron techniques in particular.
- The photon Compton scatter imaging technique is suited for one-side imaging, but in its current form provides only density images. Further development is needed if atomic-number information is to be obtained.
- Photon scattering provides better image spatial resolution than neutrons, due the relative ease of collimating photons.
- In a mobile imaging device, the use of a system that is not very sensitive to positioning information becomes essential. Systems using time-of-flight measurements should therefore be avoided.

To summarize, if there is emphasis on obtaining good elemental-composition information, neutrons should be used. On the other hand, if one desires a good image, photon scatter imaging should be employed. The first approach is more costly and technically demanding than the latter

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5.1 Photons
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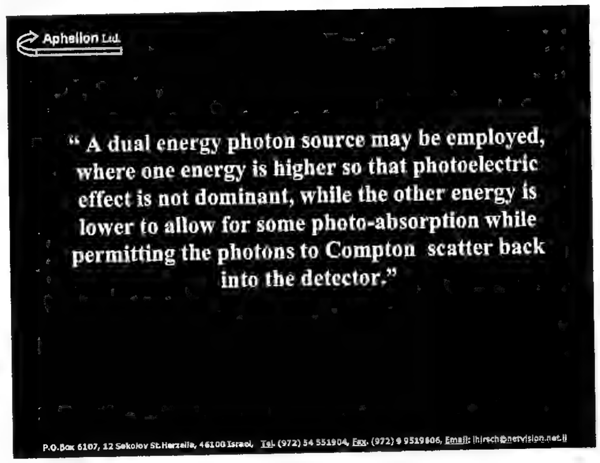
Aphelion Ltd.
" A dual energy photon source may be employed, where one energy is higher so that photoelectric effect is not dominant, while the other energy is lower to allow for some photo-absorption while permitting the photons to Compton scatter back into the detector."
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Aphelion Ltd.
Thank You
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An emerging analytical technology for military and homeland defense applications

Russel HARMON, U.S. Army Research Office, USA

LIBS: An Emerging Analytical Technology for Military and Homeland Defense Applications

Russell Harmon[1], Andrzej Miziolek[2], Frank DeLucia[2], Kevin McNesby[2], and Barrie Homan[2]

[1] US Army Research Office
[2] US Army Research Laboratory

Army Research Office Basic Research - Exploring the Imaginable

Outline

- Laser-Induced Breakdown Spectroscopy (LIBS)
- Military Applications of LIBS
- The Landmine Detection Problem
- LIBS Analysis of Explosives
- LIBS Analysis of Landmines
- LIBS Analysis of Chemical Warfare Agents
- The ARL Explosives/Landmine Detection Concept
- Summary

What is LIBS ?

- Laser Induced Breakdown Spectroscopy (LIBS) is basically a simple spark spectrochemical technique utilizing a laser source which has broad capability for both chemical and biological analysis
- In order to do LIBS one needs:
  - → Short pulse (20 nsec or faster) laser with a minimum energy of 10 milliJoules per pulse
  - → Optics for laser light delivery/focusing
  - → Optics for capturing the light emitted from the spark
  - → A detector or spectrometer to separate the light signal produced by different chemical species (e.g. elements, ions, and molecular species) for identification and quantification
- Additional information at: http://www.arl.army.mil/wmrd/LIBS

Laser Induced Breakdown Spectroscopy

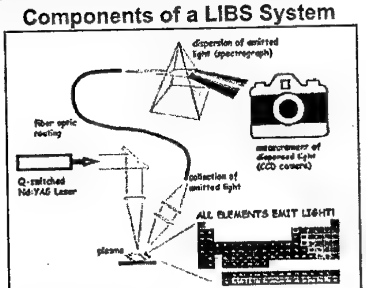
LIBS Fundamentals

Laser Induced Breakdown Event

- Plasma Formation
  - → Multiphoton absorption leads to elemental ionization
  - → Absorption of laser radiation by free electrons
  - → Electron collisions leads to ionization, heating, and breakdown
  - → Typical gas temperatures, ca. 20,000°K
- Spectrochemical analysis is based on collection of light emission (200 - 980 nm) from atomic, ionic, and molecular constituents, usually after the plasma continuum radiation decays (~ 1 μsec after laser pulse)
- All elements emit in the 200-980 nm region
- Analyte identification and abundance determination is based on measured wavelength (elemental emission lines) and intensity of captured light

Laser Induced Breakdown Spectroscopy

Components of a LIBS System



Detectors can identify anything
LIBS can identify any known substance, in principle, from what's in a

Recent LIBS Breakthrough

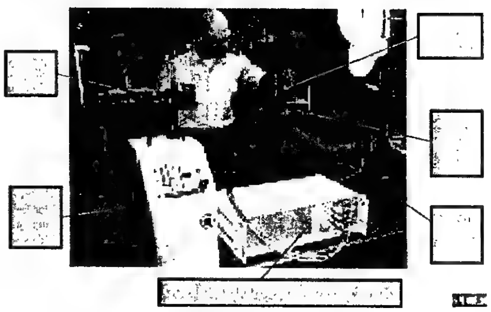
In March 2002 there was a breakthrough in LIBS component technology with the launching of the

LIBS 2000+ Broadband Spectrometer

by Ocean Optics, Inc. This commercial product was the result of a collaborative effort between ARL and OOI. This new spectrometer allows for real-time detection of all elements in any unknown target.

- 7 high resolution spectrometers
- Spectral range 200-980 nm,so all of plasma light is captured
- Expands the utility of LIBS to molecular detection
- Spectral resolution of 0.1 nm
- Full information content obtained at high resolution resolution, *i.e.* Full Spectrum Analysis
- Rugged and robust design
- Potential for field use (needs to be made lighter and smaller)

Current ARL Laboratory LIBS Experimental Setup Using the OOI LIBS 2000+ Broadband Spectrometer



Potential Military Applications for FP LIBS

- Robotic sensor battlefield applications (e.g. standoff and point detection of chemical-biological warfare agents)
- Detection of hazardous vapors (e.g. halon replacements)
- Detection of Resource Conservation and Recovery Act (RCRA) toxic metals in soils and waters
- Detection and depth profiling of Pb in paint
- Detection of depleted uranium (DU) in aerosols/particulates
- Rapid field detection of unknown, possibly hazardous material
- Field detection of contaminated debris from test ranges and military building demolition
- Field detection of excessive engine wear and approach to material/alloy failure
- Exposure testing of new materials in extreme climates
- Detection of energetic explosive materials
- Detection of landmines/unexploded ordnance (UXOs) through identification of nature of buried solid objects (e.g. rock, glass, steel, plastic, etc.) and explosives particles
- Detection of chemical warfare agents

The Landmine Detection Problem

Mines of different kinds, sizes, shapes, & materials

→ *Broad Threat*

- Over 2,800 types of AP & AT mines in use around the world
- Booby traps & UXO add to complexity
- Plastic cases & new fuse technologies

Variety of soils and environments

Man-made objects similar to mines

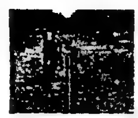
- Landmines consist of a casing and an explosive charge
- Ideal detection would detect both components

Casing	Explosive
metal	TNT
plastic	RDX
wood	

Landmine Detection

A Difficult Problem

- A broad threat: i.e., a wide range of metal, low-metal and non-metal anti-personnel and anti-tank mines
- There is no single technology or approach that will apply to all field situations



Sensor Issues:

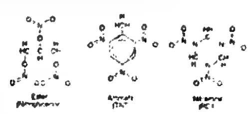
- Variability in mine character (AP to AT mines & high-metal to non-metal character)
- High degree of natural and anthropogenic clutter resulting in high false alarm rates
- Variable, heterogeneous, and dynamic character of the soil environment
- Operator use, dwell time, & signal cognition
- EMI: metallic clutter
- GPR: ground bounce
- NQR : RFI susceptibility & very high power need
- Fusion of data information from different sensors
- Low vapor pressures of explosives for sniffing
- Vapor anomalies not over landmine

Is there a role for LIBS in Landmine detection?

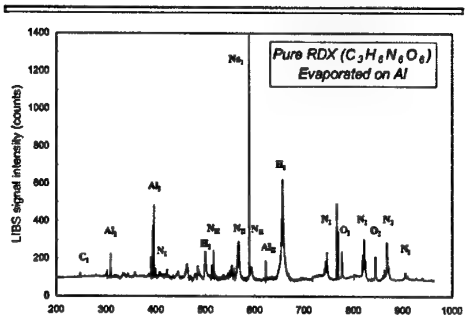
LIBS Analyses of Explosives

Some Common Explosive and Energetic Materials

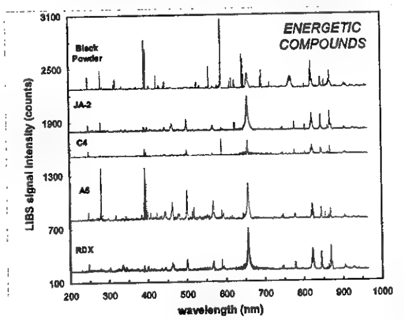
- Black Powder
- Ammonium Nitrate
- TNT: $C_7H_5N_3O_6$
- RDX: $C_3H_6N_6O_6$
- HMX: $C_4H_8N_8O_8$
- Comp A3: *91% RDX, 9% candelilla wax*
- *Comp A-5: 98.5% RDX, 1.5% stearic acid*
- Comp B: *60% RDX, 39% TNT, 1% wax*
- Comp C4: *91% RDX, 9% plasticizer [5.3% di(2-ethylhexyl)sebacate, 2.1% polyisobutylene, 1.6% motor oil]*
- JA-2: *60% nitrocellulose, 15.8% nitroglycerine, 26.2% plasticizer [diethylene glycol dinitrate], 0.74% Akardite II [N-methyl-N',N'-diphenyl urea] burning rate moderator and stabilizer], 0.05% magnesium oxide, 0.7% graphite,*
- M-43 - 17 perf: *76%RDX, 4% nitrocellulose, 12% cellulose acetate/butyrate, 8% plasticizer, <1% additives*
- XM39: 76% RDX, 4% nitrocellulose 4%, 7.6% acetyl triethyl citrate, 12% cellulose butyrate, 0.4% ethyl centralite [N,N'-diethyl carbanilide] propellant stabilizer
- PBX 9502: *95% TATB (triaminotrinitrobenzene), 5% Kel-F 800*



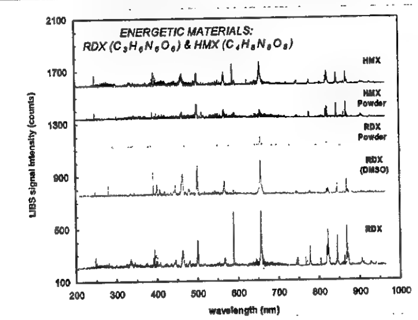
LIBS Analyses of Explosives



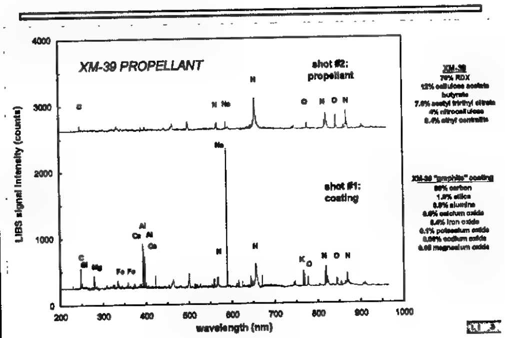
LIBS Analysis of Explosives



LIBS Analyses of Explosives

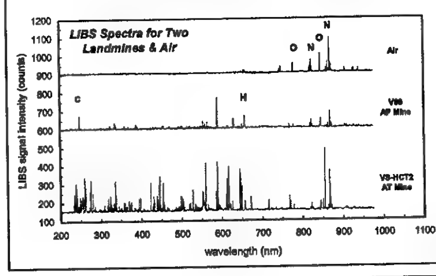


LIBS Analyses of Explosives

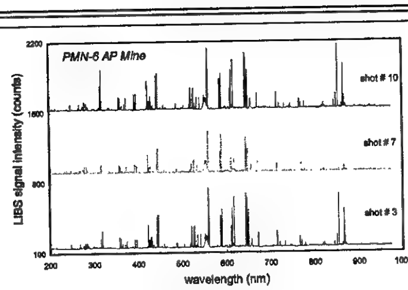


LIBS Analysis for Landmines

Spectral Differences for Landmine Casings

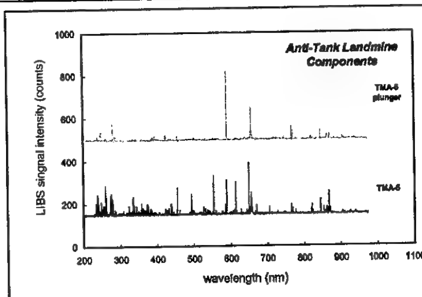


LIBS Analysis for Landmines

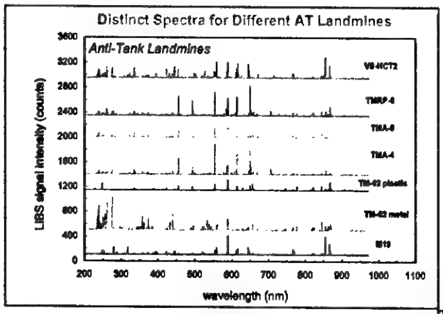


Full LIBS Spectra Are Very Reproducible

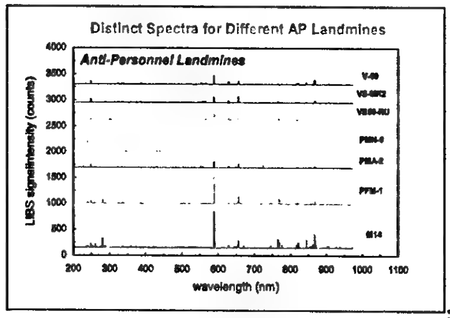
LIBS Analysis for Landmines



LIBS Analysis for Landmines



LIBS Analysis for Landmines



LIBS Analysis for Chemical Warfare Agents

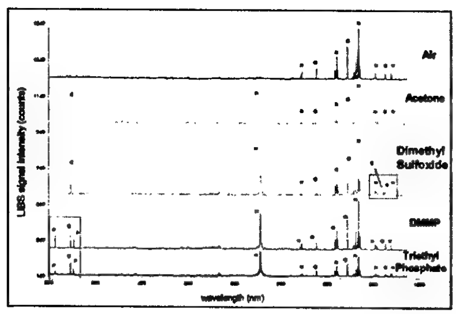
Chemical Agent	Constituent Elements
GB (Sarin)	P, F, O, C, H
VX	P, S, N, O, C, H
HD (Mustard)	S, Cl, C, H

Target Elements (besides H, C, N, and O)

Element Emission λ

- *Sulfur* **Containing Compounds** (λ: 921 nm)
  - VX
  - Mustard Gas
- *Phosphorus* **Containing Compounds** (λ: 213, 253 nm)
  - VX, GA, GB, GA
- *Chlorine* **Containing Compounds** (λ: 800-920 nm)
  - Mustard Gas
- *Fluorine* **Containing Compounds** (λ: 670-720 nm)
  - GB, GD

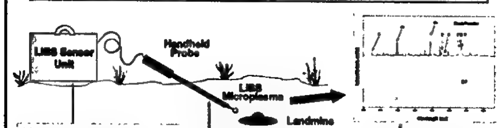
LIBS Spectra for Chemical Agent Simulants



Future Directions for Field Brtable LIBS

- **We are optimistic for the development of a field- portable LIBS system for military and homeland defense applications**
- **However, specific improvements are needed:**
  - Size - The current system should be reduced in size by at least 50% (i.e. shoebox size)
  - Weight - Lightweight materials should reduce the weight of the current system by a factor of 5 (i.e. to 10lb or less)
  - Laser - Nd:YAG laser and fiber-optic delivery system needs to be redesigned to fit into a handheld probe
  - LIBS Spectral Reference Library - A reference library of LIBS spectra for target materials needs to be greatly expanded
  - Chemometrics - A fast and robust software is needed for for spectral matching and manipulation, element identification and stochiometry calculation

Concept of LIBS Sensor for Landmine Detection



Field Portable LIBS Sensor

- Compact - briefcase size or smaller (with portable power)
- Rugged and robust
- Real-time response
- No sample preparation
- High sensitivity - nonogram or lower detection limits
- Low cost, high performance
- LIBS sensors can be developed for standoff detection

Handheld Probe

- Laser in handle, fiber-optic pickup of spark emission
- Can be made flexible using fiber optics for interrogating samples in out-of-the-reach areas
- Analyzes solids, particles, liquids, and gases
- Analyzes unknowns on soils, surfaces, in liquids, and beneath surfaces
- Used for materials analysis

LIBS Spectral Analysis

- Real-time response (1 sec)
- Detects and identifies both the composition of an object (e.g. a landmine) and its contents (e.g. the explosive)
- Compare with library of LIBS spectra.
- Information in digital form
- Wireless communication with command center possible

Defense Emergency Relief Fund LIBS Initiative

- FY03 initiative at ARL for the development of a field-portable LIBS system for security and homeland defense applications
- 1st prototype available in late 2003

- Design Goals:
  - → Size - medium size backpack
  - → Weight - 25 lbs or less
  - → Probe- hand-held (mini-laser in handle), interchangeable lengths
  - → Display- eyeglass mounted VGA resolution
  - → Spectrometer- broadband (200-980 nm), new design, small shoebox,
  - → Sample rate- laser shot every 3-4 seconds

Summary

LIBS Attributes for Military & Security Applications

Laser Induced Breakdown Spectroscopy (LIBS) is an emerging sensor technology for military applications with unprecedented performance characteristics:

- Real-time response
- No sample preparation
- Inherent high sensitivity (nanogram)
- Can be used as a point sensor or in a standoff detection mode
- Sensitive to all chemical elements (therefore, the only sensor that is capable of detecting and identifying different types of hazardous matter)
- Can be made small (shoebox size) and lightweight (10 lbs or less)
- Can be soldier portable, or mounted on a combat/robotics platform
- Can utilize a hand-held rigid probe, or use flexible optical fibers, to access and analyze targets in out-of-reach locations
- Standoff distances of 20-50 meters and beyond are possible (scales with laser size)
- LIBS detection of explosives (including black powder, C4, RDX), energetic materials, landmine casings, chemical agent simulants (DMMP, DIMP), biological agent surrogates (BC, BG, BT), and toxic metals has already been demonstrated

Improvement of nitrogen NQR detection in explosives by proton polarization

Tomaz APIH; Robert BLINC, Institute Jozef Stefan, Slovenia

Detection of explosives by quadrupole resonance

T. Apih, R. Blinc

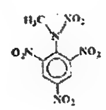
J. Stefan Institute, Ljubljana, Slovenia
FMF, University of Ljubljana, Slovenia
Institute for Mathematics, Physics and Mechanics in Ljubljana, Slovenia
King's College London, U.K.
International Trust Fund for Demining, Ig, Slovenia

Current mine detection technology

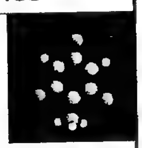
- Metal detectors:
  - high false alarm rate
  - have difficulties detecting low metal content antipersonnel mines
- Mechanical (manual) prodding:
  - slow
  - dangerous
- Alternative detection techniques: not mine specific - can be triggered by a similar object
- Need for a better detection technology - --> direct explosive detection

Explosives in landmines

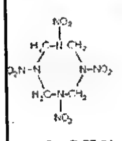
RDX - $C_3H_6N_6O_6$



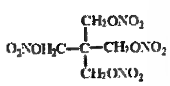
Tetryl - $C_7H_5N_5O_8$



TNT - $C_7H_5N_3O_6$ (80-90% of mines)



HMX - $C_4H_8N_8O_8$



PETN (Penta) - $C_5H_8N_4O_{12}$

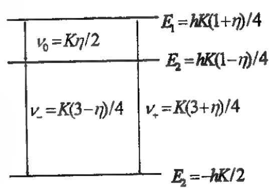
All relevant explosives contain nitrogen!

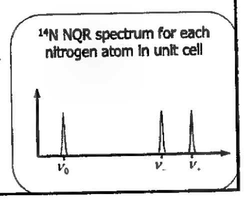
^{14}N (I=1) energy levels in zero field

$$H_Q = \tfrac{1}{3}K\left[3I_z^2 - I(I+1) + \tfrac{1}{2}\eta(I_+^2 + I_-^2)\right]$$

quadrupole coupling constant: $K = eQV_{zz}/h$

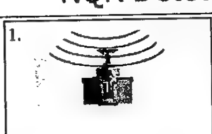
assymetry parameter: $\eta = (V_{xx} - V_{yy})/V_{zz}$





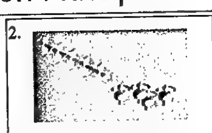
NQR Detection Principle

1.



Transmitter emits RF waves.

2.

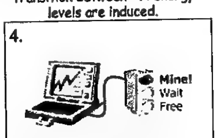


Transition between ^{14}N energy levels are induced.

3.

^{14}N nuclei emit RF waves at substance specific frequencies.

4.

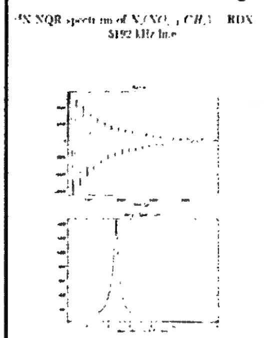


Signal is received and analysed by PC. If explosive is detected, audio-visual signal is triggered.

Remote ^{14}N NQR Detection?

- Advantages:
  - molecular specific: $0.5\ \text{MHz} \le (eQV_{zz}/4h) \le 10\ \text{MHz}$
  - virtually zero false alarms
  - detects zero metal content landmines
  - no need for magnetic field
- Disadvantages:
  - need for high power RF amplifier
  - low sensitivity (signal accumulation)
  - RF interference (gradiometric coils)
  - does not detect liquid explosives or explosives contained in metal cases (but could be used in MD mode!)

^{14}N NQR of RDX



- Relatively high frequencies - good sensitivity
- T. shift: 50-500 Hz/K
- Short T_1 (~ 10 ms) - fast repetition and accumulation possible
- SSFP pulse sequence - Steady State Free Precession
- Remote NQR detection possible

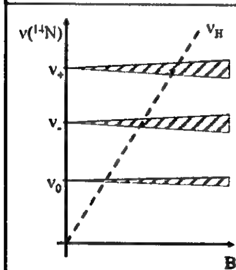
TNT Problem (80-90% of mines!)

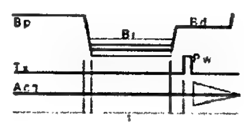
- 6 nonequivalent N-14 sites
  - monoclinic (yellow, stable) modification
  - orthorhombic (white, unstable) modification
  - ratio of monoclinic/orthorhombic ratio depends on the processing technique
- low frq.: ν_+ (800-900) kHz, ν_- (700-800) kHz
- long T_1 (2s - 30s)
- S/N ratio to low for conventional detection in the required time!
- How to increase ^{14}N NQR signal to make the detection useful?

Ways to detect ^{14}N NQR

- *A: Indirect detection:* quadrupole dips in proton relaxation
- *B: indirect detection by* Nuclear Quadrupole Double Resonance
  - B1: ^{1}H ^{14}N NQDR with field cycling
  - B2: NQDR with multiple frequency sweeps
- *C: direct detection by* enhancement of ^{14}N-NQR signal (*lecture by Lužnik & Trontelj*)

A: Quadrupole dips



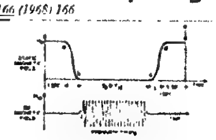


- Cross-relaxation when $\nu_P(B_R) = \nu_Q$
- Disadvantage:
  - low resolution due to Zeeman broadening of ^{14}N lines in powders

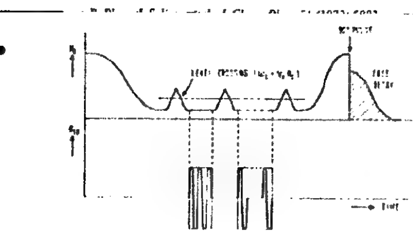
B1: ^{14}N-^{1}H NQDR with field cycling

Slusher, Hahn Phys. Rev. 166 (1968) 166

- Steps:
  - H polarized in strong B_0
  - adiabatic demagnetization
    - "cold" (polarized) protons
  - rf irradiation: in resonance $\nu_{rf}=\nu_Q$, energy flow from "hot" (saturated) N to H
  - stepwise rf irradiation, reduction of the proton signal when $\nu_{rf}=\nu_-$, ν_+, or ν_0

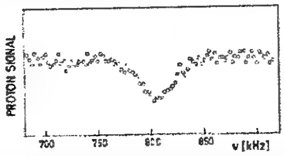


Multiple Level Crossing Cycle



Increase of energy transfer between the proton and the nitrogen system by multiple level crossing

^{14}N-^{1}H NQDR with field cycling



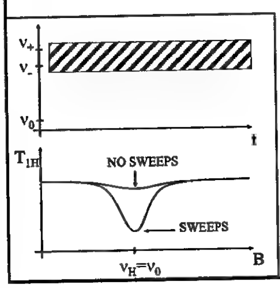
- ^{1}H-^{14}N nuclear quadrupole double resonance spectrum of TNT in zero external magnetic field (ν_+ NQR transition).
  (The proton signal vs. the frequency of the rf irradiation field.)
- Disadvantage:
  - broadening: "spin quenching" in zero field due to averaging of magnetic dipole coupling of quadrupole nuclei with $\eta \neq 0$

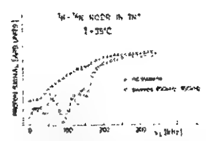
B2: NQDR with multiple frequency sweeps

Seliger, Žagar, Blinc, J. Magn. Res. 106, 214 (1994)

- Better resolution and higher sensitivity:
  - Adiabatic field cycling between B_p and small $B_0>0$ so that $\nu_L(^1H) \sim \nu_Q(^{14}N)$
  - continuous sweep of rf frequency in a range, covering both ν_+ and ν_-
  - Result: as if NQR R_1 would be very large-- > fast flow of thermal energy from ^{14}N NQR system to "cool" proton system.
    If only one NQR frequency is covered by sweep, negligible change in the proton signal --> allows for a rough ν_+ and ν_- determination

Simulation of Fast Nitrogen Relaxation at $\nu=\nu_+(W_+)$ and $\nu=\nu_-(W_-)$ by Multiple Frequency Sweeps



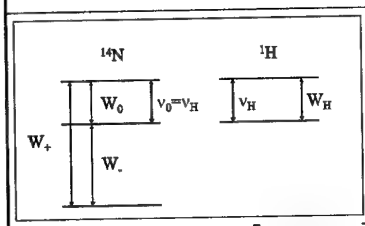


Proton signal as a function of the external magnetic field in the range of the $\nu_0=\nu_+-\nu_-$ ^{14}N NQR transition.

... even higher resolution ...

- Two frequency irradiation
  - first $\nu_1 \sim \nu_+$ is chosen and ν_2 is varied until $\nu_2=\nu_-$
  - then $\nu_2=\nu_-$ is kept fixed and ν_1 varied to $\nu_1=\nu_+$.
  - resonance $\nu_1 \sim \nu_+$, $\nu_2=\nu_-$ and $\nu_L=\nu_0$ to 100 Hz
  - very useful also in the case of complicated N 14 spectra as it allows the assignation of ν_+ and ν_- lines to a given N 14 nucleus

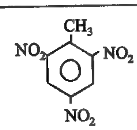
NQDR with Multiple Frequency Sweeps



$$T_{1H}^{-1}(\nu_H=\nu_Q)=W_H+\frac{N_N}{N_N+N_H}\left[W_0+\frac{W_+W_-}{W_++W_-}\right]$$

Seliger, Žagar, Blinc, J. Magn. Res. 106, 214 (1994)

TNT at room temperature



$$\frac{N_N}{N_N+N_H}=\frac{5}{8}$$

- Frequency dispersion of proton T_1
  $W_N \sim 0.2$-$0.3\ s^{-1}$
- Double resonance between laboratory and rotating frame
  $\nu_Q = 810$ kHz
  $\eta \approx 0$
- Double resonance with multiple frequency sweeps

^{14}N NQR frequencies in military grade TNT

	ν_+ [kHz]	ν_- [kHz]	e^2qQ/h [kHz]	η
1	872	712	1056	0.303
2	861 5	769	1087	0.170
3	853	742 5	1064	0.208
4	850	718	1045	0.253
5	847	755	1068	0.172
6	837	742	1052	0.179
7	~807	~807	1076	~0

NQR parameters have to be verified on a full range of TNT samples for the effects of crystallization, processing, aging, impurity content ...

Conclusions

- RDX:
  - remote detection by pure NQR is possible
- TNT
  - pure NQR probably does not have enough sensitivity for remote detection
  - NQDR: high resolution and high sensitivity, but homogeneous magnetic field is needed
  - PE NQR (see next talk) may be possible

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NATO Programme
Science for Peace

Improvement of ^{14}N NQR detection in explosives by proton polarization

Janko LUZNIK, University of Ljubljana, Slovenia

INTRODUCTION

Nuclear quadrupole resonance – NQR is one of the promising methods for the detection and identification of illicit substances [1-3]. Almost all explosives, drugs etc. contain nitrogen. ^{14}N NQR spectra and their resonance frequencies depend on the molecular structure and are characteristic of each of these substances, providing a kind of their »fingerprint« and so enabling their detection and identification. The problem is that the ^{14}N NQR spectral lines often lie at low frequencies where the NQR signals are usually very weak and not easy to detect. A lot of work has been done so far and is still in progress to improve the sensitivity of NQR detection. More sophisticated and sensitive experimental equipment can be used with application of superconducting receiving coils and cooled preamplifiers or SQUID (Superconducting Quantum Interference Devices) sensors. Various different pulse sequence methodes, proper data processing and averaging can also improve the sensitivity.

An additional method to improve the signal is polarization enhancement [4-6]: Initially protons are polarized in a strong magnetic field so that the proton NMR levels are split considerably more than the nitrogen NQR levels. Due to the Boltzman distribution factor the occupation difference between the high and low NMR levels of protons is much higher than the occupation difference between ^{14}N NQR levels. During the adiabatic demagnetization of the measured sample level crossing between proton NMR and ^{14}N NQR occurs, causing an energy flow from the »hot« nitrogen quadrupolar system to the »cold« proton NMR system which is manifested in the »cooling« of the nitrogen quadrupolar system. Applying standard pulse NQR detection techniques immediately after removing the magnetic field, the signal can be improved according to the ratio of the proton NMR to ^{14}N NQR frequency (f_p/f_Q) if the proton reservoir is abundant enough to cool down the nitrogen system to the proton spin temperature. If the abundances of the proton and nitrogen systems are comparable, the improvement factor is reduced proportionally to the ratio: $N_H/(N_H + N_N)$. When several nonequivalent nitrogens are present in the molecule, multiple level crossing must be correctly taken into account.

EXPERIMENTAL

To confirm the predicted improvement factor with the use of polarization enhancement three different samples: $N_3(NO_2)_3(CH_2)_3$ – RDX (explosive), $(CH_2)_6N_4$ – HMTA (hexamethylenetetramine) and $(NO_2)C_6H_4COOH$ – NBA (4 – nitrobenzoic acid) were tested. Approximately the same amounts of samples packed in plastic tubes of 16 mm diameter and 40 mm length were used. Proton polarization [7] was obtained by an NdFeB permanent magnet (Vacuumschmelze GmbH, VACODYM). The dimensions of the magnet were 70 mm x 70 mm x 65 mm. The very nonhomogeneous field at the site of the sample was estimated to be 200 $\pm$ 50 mT and the average proton NMR frequency was around 8.5 MHz. To avoid fast quadrupolar relaxation of ^{14}N the experiments were performed at 77 K. All the samples were polarized for at least 10 minutes to assure complete proton polarization even at very slow spin – lattice relaxation. After polarization the magnet was quickly (manually) removed and single shot ^{14}N NQR FID signals were recorded and compared to those without polarization.

RESULTS

The results of our measurements are collected in Tab. 1, where A_c and A_m represent the calculated and the measured enhancement factor of the ^{14}N NQR signal intensities. The agreement between the calculated A_c and observed enhancement A_m is very good. It

demonstrates that the use of proton polarization enhancement at a fixed polarization field is much more effective at lower frequencies where the ratio of the proton NMR to ^{14}N NQR frequencies is higher. As was expected, the polarizing magnetic field homogeneity is not critical and the improvement is proportional to the average field only.

sample	f_Q (kHz)	f_P/f_Q	$N_H/(N_H+N_N)$	A_c	A_m
RDX	5265	1.6	0.75	1.2	observable(1.3)
HMTA	3408	2.5	0.75	1.9	around 1.8
NBA	982	8.7	0.85	7.4	around 7

Table 1. Calculated and measured data for 3 different samples. All measurements were made at 77 K.

CONCLUSIONS

- The use of proton polarization enhancement of ^{14}N NQR signals at low frequencies can be effective.
- Because the improvement is proportional to the polarizing magnetic field, the metod is usefull only if strong enough magnetic field can be obtained on the place of the sample.
- Inhomogeneity of the field is not critical.
- ^{14}N NQR relaxation must be slow enough to allow the removal of the magnet or the sample.
- The ratio of protons to nitrogens in the sample must not be small (For most of explosives and drugs this condition is fulfilled).

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Explosive Detection in Mine Clearance: Chemical behavior of explosives and their vapours in the field.

Vernon JOYNT, CSIR, South Africa

Introduction

During the recent SPIE Conference in Orlando I had the privilege to attend lectures on Chemical detection of explosives and mines. This covered the behavior of these explosives in the soil. There were related mine detection lectures based on vapor detection.

In Africa I attended the REST (Remote Explosive Sensing Techniques) workshop at Morogoro in Tanzania. This workshop was attended by top chemists from Nomadics (Dr Mark Fischer), Sandia National Laboratories (Dr Jim Phelan) and FOI (Lena Sarholm). The world REST fraternity was also well represented: The Geneva International Centre of Humanitarian Demining (GICHD) who was running the workshop under Håvard Bach, APOPO under Christophe Cox, Mechem with Kip Schulz, NOKSH and NPA with Rune Fjellanger. There was also an excellent summary of the workshop presentations issued by Dr Ian McLean of the GICHD.

I was fortunate to have been given copies of all the mentioned people's lectures apart from having attended the presentations.

In Europe I was asked to review 8 lectures proposed for the forthcoming EUDEM-Symposium in September. Obviously these must remain confidential till presented but they did help remind me of the advances made and also the mistakes that are holding Vapor Detection back in terms of becoming a valuable demining tool.

I will however use some of the points made and slides used constructively in this closed expert workshop.

Approach

I would like to separate the techniques

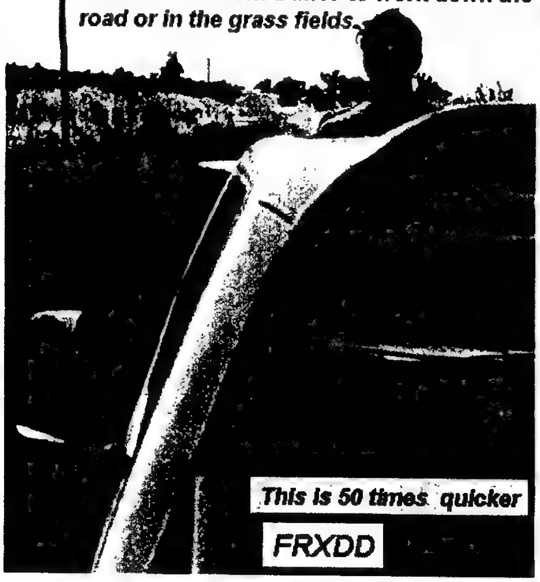
MINE DETECTING DOGS (MDD)

- At a large workshop here in Ljubljana some years ago the case for MDD was debated. No consensus was reached. There were just too many opinions, stresses and uncertainties.
- The work group at the GIHD started basically with the same problems but through the persistence of Håvard Bach and others the problems became less and the Dog People started co-operating.

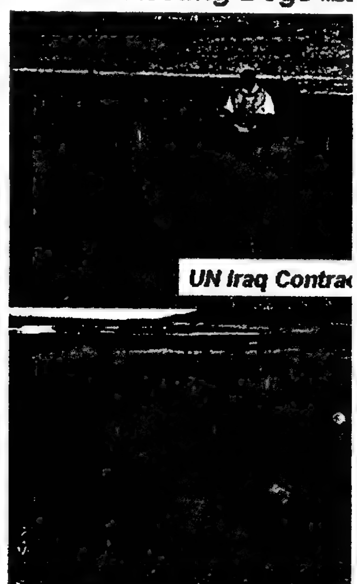
A MDD AND HANDLER WORKING AT ROAD CLEARANCE

SOME MDD VARIATIONS

Not like the MDDog working in safe lanes and blocks on the right, these two TNT detecting Free roaming dogs are voice commanded from a MRV to work down the road or in the grass fields.



Mine Detecting Dogs MDD



Safe lanes for the dog handler takes time to make

REST (MEDDS)

- The old Mechem was part of that GICHD MDD effort and I pushed our Mechem Explosive and Drug Detection System MEDDS) with a passion. It was only accepted once the South African Government offered the use of the system to all HD operations with no strings attached.
- The technology in this context was first transferred to NPA who named it Explosive Vapor Detection (EVD) and then later Håvard Bach renamed and broadened the concept to REST
- MEDDS was more scientifically controllable because the training and use of the dogs were separated from the field and sampling problems

- With MDD setting up controlled tests was extremely difficult when one is trying to do this in real operational demining conditions. With MEDDS this was easier and the results more acceptable.
- MEDDS resulted in us partaking in the DARPA Electronic nose project. This project deliver two significant products:
    - The Nomadics/MIT FIDO electronic nose
    - The Quantum Magnetics NQR explosive detector
- A NVESD Contract over the past two years with the new Mechem and Nomadics attempted to repeat more scientifically what the original development and demining contracts had taught us about the system. They had some success.
- MEDDS taught us many things about MDD and their problems but most important of all it taught us the problems of what happens to the explosives once they are out of the landmine and left to the environmental influences. A nightmare!
- MEDDS was often used to provide a dog-nose benchmark to a Vapor sensor development or evaluation.
- Many unresolved arguments resulted as to the sensitivity levels that a dog's nose can achieve. According to Jim Phelan and us, dogs in Mechem and Global (San Antonio) could do ppq (Quadrillion). This is detecting 10 to the power –15 grams of TNT or femtograms. A picogram is 10 to the power -12 grams so dogs are at least a 1000 times below classic chemistry which can normally do picograms.
- Nomadics have however now cast some doubt on the way this figure was measured. And so it goes on.

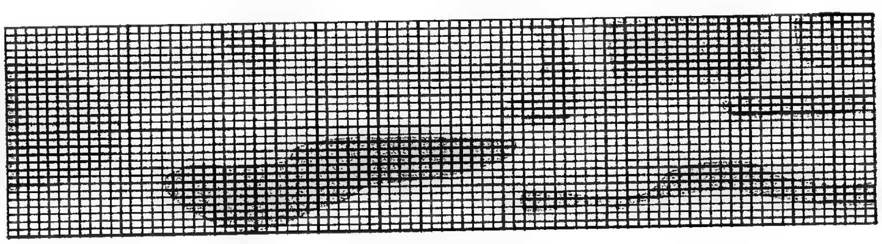
EXPLOSIVES IN SOIL

The explosives leak and leach out of buried mines and then spread out into and onto the surrounding soil. How does it spread? Where does it find itself after a time? What happens to it in different conditions? A million questions but the mere fact of MDD successes made it important to study this.

This has been a bug bear all along and in the early 1990's we tried to establish how the contours of detection around a buried mine or mines looked like. The shape we established, I described later could be as irregular as a camouflage pattern.

Compare this with the lines determined during one NVESD test in Croatia recently:

Area Reduction test site May/September 2002



Coloured areas represent standing and flowing water up to 40 cm deep

Although this represented standing water, tests done showed the TNT to be strongest in the water. This is to be expected because TNT is about a million times more soluble in water than in air.

What is important is to note that when the water dried up the spread of TNT could have remained in that shape.

This would explain the so called 'camouflage' patterns we had determined ten years before.

The scientific tests and results obtained in the early 1990's by the old Mechem was never published and only recorded in broad detail. What was shared was the results and developed techniques.

Today as people realize the value of this tool they want more precise recorded results and sound conclusions. I have personally been part of some of these new tests. Only on occasion have 'new to us' results appeared. Some of these could explain problems we sometimes encountered in the clearance contracts.

So it is fair to say that the whole field of REST is improving and moving forward.

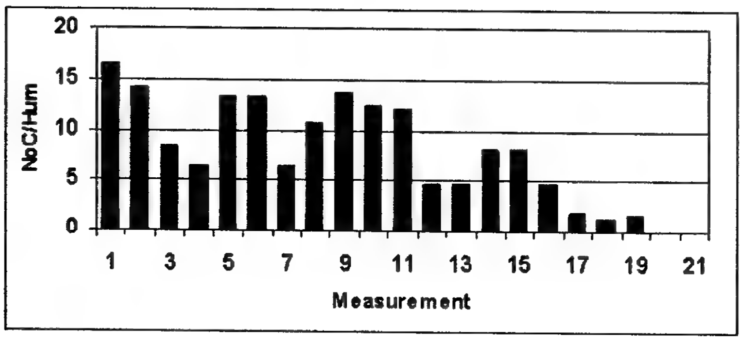
Showing some Morogoro slides can illustrate this; a FOI slide:

Why analysis of soil samples?

- **Mapping of explosives migration in soil and air**
- **Verification of explosives/land mine detection systems**
- **Detection of landmines**

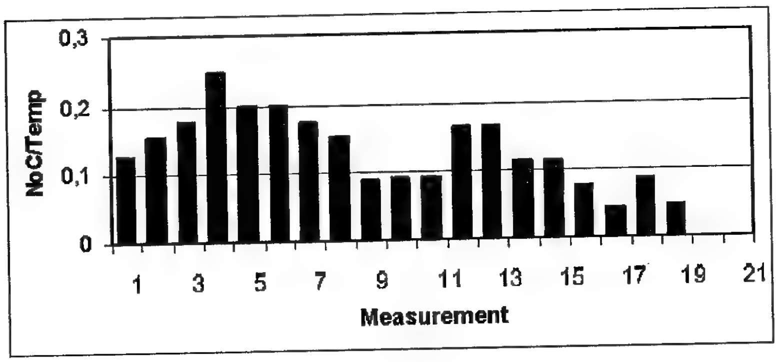
And some 'new to us' results; from NOKSH:

Relationship between Humidity and proportion correct



High correct=low humidity
Spearmans r = 0.44, P=0.044

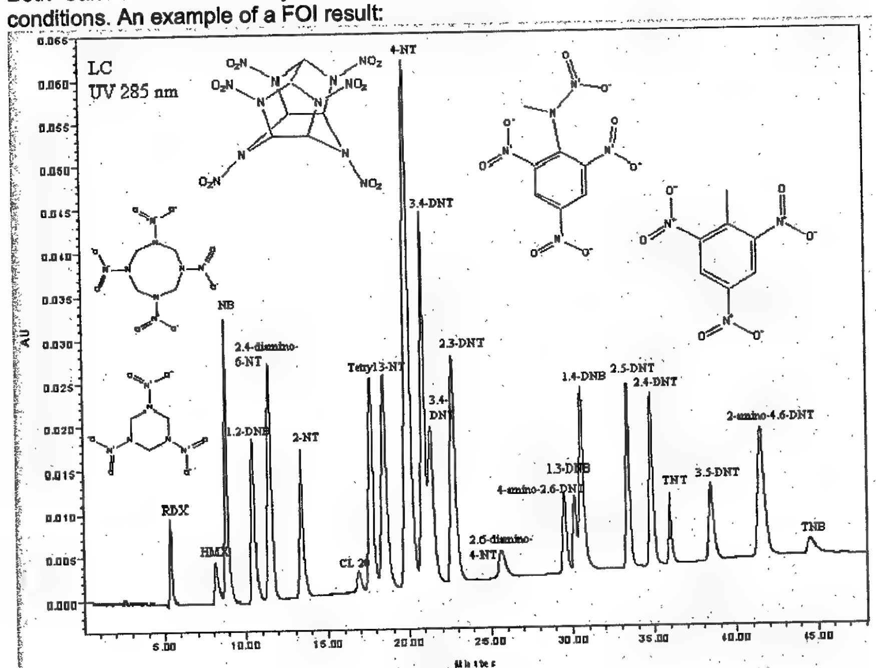
Relationship between Temperature and proportion correct



Little relationship between T and proportion correct
Spearmans r = 0.19, NS

We used to believe MEDDS worked better in humid conditions and avoided hot dry conditions. This came from our MDD experiences. Dogs smell better when the humidity is above 30% but REST is sampled with a pump and filter that then is presented to a dog in a humidified room.

Both Sandia and FOI analyzed the decomposition products of TNT in various soils and conditions. An example of a FOI result:



These are products extracted out of soil contaminated with TNT, RDX and TETRYL.

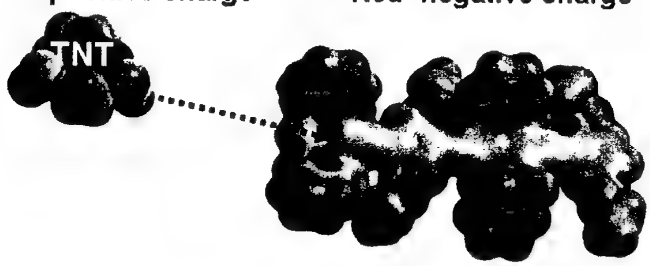
For TNT a decomposition product that had a longer half life in the soil was 4 Amino Dinitrotolueen so in doing area\reduction one should include this product.

CHEMICAL MACHINES

Nomadics FIDO: This uses a sensor polymer developed at MIT

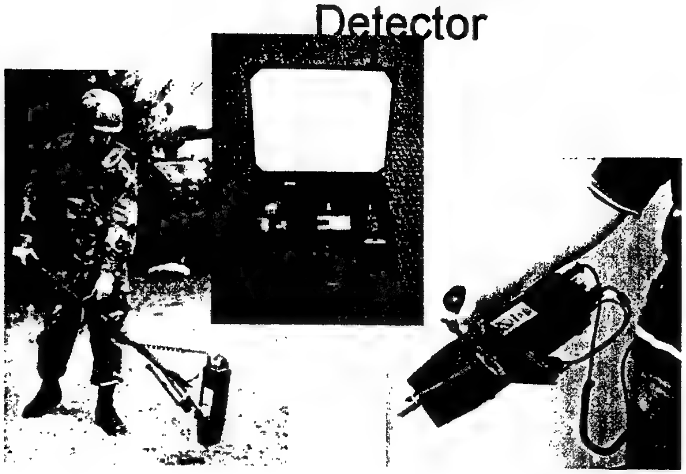
Enhancing Polymer Selectivity

Blue=positive charge **Red=negative charge**

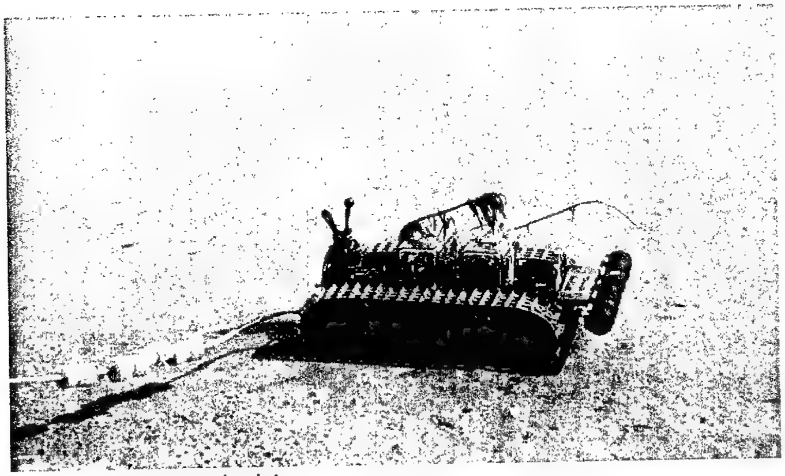


Polymer contains binding sites that are engineered to be electrostatic 'mirror images' of target analytes - this enhances selectivity toward target analytes.

Handheld Explosives Detector



Underwater Detection of TNT



The company is now also into:

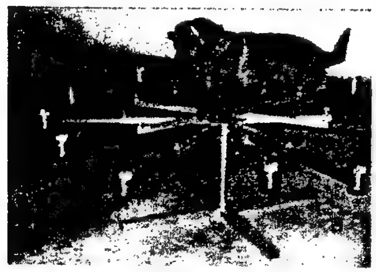
Other Work in Progress

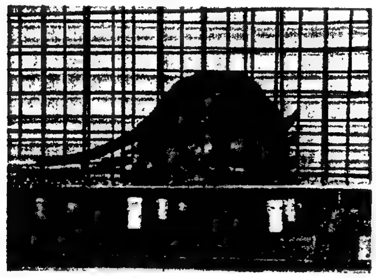
- Environmental screening for explosives contamination on firing ranges
- Screening of scrap materials from firing ranges for detonable masses of HE
- Chemical warfare agent detection
- Biological warfare agent detection
- Gunshot residue detection
- Groundwater monitoring for explosives contamination
- Detection of other explosives

One needs also to show the APOPO rats and mention they are also using the rats to detect Tuberculosis. So biological detection is on the cards for REST.

General Methodology

Training and analysis





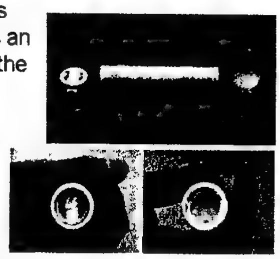
The CSIR, in collaboration with a US company, is detecting Cancer in humans by using dogs and the ScentPrint two stage filter system the CSIR has developed for multiple uses of REST. The US Company has already some trained dogs doing the Cancer work and the addition of a filter step has shown an improvement.

The CSIR is also involved with TB diagnosis but lacks an animal training Company as a partner.

ScentPrint: A Two Stage REST Filter System

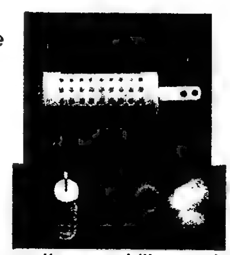
Tube ready to use

- Removal of the lids allows one to pass an air sample trough the vapor tube



The Inner Tube

- The inner tube is perforated to release the trapped vapor sample. The tube is also designed to house any vapor capturing material suited for the appropriate circumstance.



The inner tube is a holding reservoir with strong <u>ab</u>sorption while the cotton wool-like wads have the correct surface <u>ad</u>sorption properties. This is to hold enough transferred reservoir material ready on the surface of the wool for the hot moist animal breath to <u>de</u>sorb the smell and get it into his nose.

An APOPO rat
Here one can see why one of the foremost dog trainers in the world for REST dogs asked me to set him up with a program to train Dachshund to operate like the APOPO rats; on a shelf around the walls of a room! He claims savings in man power and test time will make it worth it. Off course the dogs would not need a cage but a railing not to fall off would do. According to him. A hunting dog like a Dachshund has a good nose and is trainable.

APOPO is also running a rat detection program to do TB diagnosis. For this they found a second stage adsorber that works better than the Mechem filter, to be polyester wool.

The CSIR found that similar polyester wool coated with a silicone polymer was best for Cancer detection's second stage in the ScentPrint filter. On their TB program the CSIR has no animals to do their testing so a talk to APOPO seems appropriate.

Scientifically the filter problem is that a good absorber is a good reservoir for large quantities of the active chemical or bouquet vapors. This seldom is a good adsorbent for releasing the ingredient to the animal when it smells. Good adsorbents often hold to little sample for a series of animals to make passes and one then finds the second stage 'fading'. So the second stage can have more than one 'wool filter' to use in sequence of smelling.

Now you see why Jim Phelan has coined the word 'sorption' so one need not specify!

Chemical detectors can and are using filters in mine detection to do a similar function; to concentrate samples and also to separate the rough and tumble of field sampling from the analysis step. The various companies use different solutions but inevitably they have to have a holding stage followed by a quick release into the detector. Like the cold finger and flash heater of commercial chemical analyzers.

Demands on chemical vapor detection of landmines and explosives for counter-terrorism

Michael KRAUSA, ICT, Germany

Demands on chemical detection of landmines and explosives for counter-terrorism

Demands on chemical vapor detection of landmines and explosives for counter-terrorism

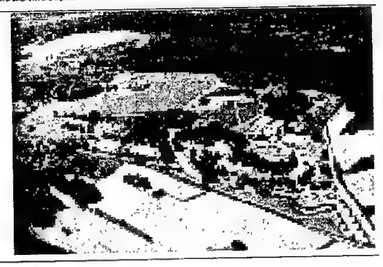
Picture:
DARPA, Dr. Gary Settles,
Penn State University

Michael Krausa
Applied Electrochemistry
Fraunhofer-Institut für Chemische Technologie

Fraunhofer Institut Chemische Technologie

Demands on chemical detection of landmines and explosives for counter-terrorism

Fraunhofer
ICT
Pfinztal



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Demands on chemical detection of landmines and explosives for counter-terrorism

Finanzen
Personal
Organisation

Forschungsplanung
Kommunikation
Internationale Aktivitäten

Synthese
Reaktionstechnik
Formulierung
Compounding
Analytik
Partikeltechnik

Systementwicklung
Modellierung Verbrennung
Schnelle Meßtechnik
Gasgeneratoren
Sicherheitstechnik

Batterietechnik
Brennstoffzellen
Sensoren
Elektrokatalyse

Umweltfreundliche
Produktionsverfahren
Entsorgungsverfahren
Kreislaufwirtschaft
Umweltsimulation

Produkte
Werkzeugtechnik
Verarbeitung
Werkstoffe

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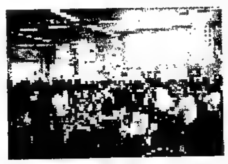
Demands on chemical detection of landmines and explosives for counter-terrorism

Problem: Fast detection and location of explosives



airport hall

mined garbage dump in Sarajevo

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Demands on chemical detection of landmines and explosives for counter-terrorism

Today: Fast detection (smelling) and localization by sniffer dogs

Photo by: Geneva International Centre for Humanitarian Demining

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Demands on chemical detection of landmines and explosives for counter-terrorism

Basic demands on Sensors

<u>for mine detection</u>

- easy to handle
- handheld
- robust
- cheap
- all climates
- maintenance free
- low-power consumption

<u>for counter-terrorism</u>

- fast
- trained staff
- handheld

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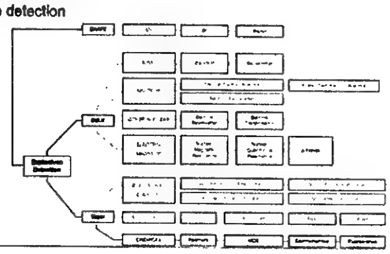
Explosive detection



Explosives used

Most of the mines are filled with 2,4,6-TNT

World Trade Center 1993
Nitrated urea

Oklahoma City 1995
Ammonium nitrate fuel oil (ANFO)

Moscow1999
presumable cyclonite

Suicide bombs Home made explosives

Which explosives are used? (from K.G. Furton and L.J. Myers)

Commonly used explosives	Main components
C-2	RDX+TNT+DNT+NC+MNT
C-3	RDX+TNT+DNT+Tetryl+NC
C-4	RDX+Polyisobutylene+Fuel oil
Cyclotol	RDX+TNT
DBX	TNT+RDX+AN+Al
HTA-3	HMX+TNT+Al
Pentolite	PETN+TNT
PTX-1	RDX+TNT+Tetryl
PTX-2	RDX+TNT+PETN
Tetrytol	TNT+Tetryl
Dynamite 3	NG+NC+SN
Red Diamond	NG+EGDN+SN+AN+Chalk

Vapor pressures of common explosives

Explosives	Vapor pressure (Torr) at 25°C
EGDN	$2.8x10^{-2}$
NG	$4.4x10^{-4}$
TNT	$7.1x10^{-6}$
PETN	$1.4x10^{-8}$
RDX	$4.6x10^{-9}$

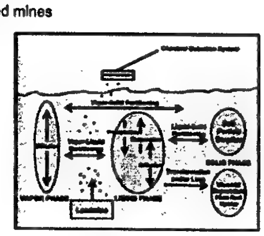
The vapor concentration decreases with increasing distance from the source.

Vapor pressures

Chemical	Vapor pressure (Torr) at 25°C
Ammonium nitrate	No information found
Nitrated urea	No information found
Potassium perchlorate	No information found
Cane sugar	No information found

TNT-distribution around buried mines
Sandia National Labs

Depending on different transport mechanism the highest TNT-surface concentration is not necessarily found directly above the mine!



Demands on chemical detection of landmines and explosives for counter-terrorism

Vapor concentrations above buried TNT (US Corps of Engineers)

Sampling of the vapor above military grade TNT

- Time
- Temperature
- Moisture
- Different soils

Analyte (pg) collected in 1 minute after 6 days at 23 °C

Sand	Air dry	2.1% moisture	3.1% moisture
1,3-DNB	29.3	561	285
2,4-DNT	2.36	754	441
2,4,6-TNT	0.267	20.8	13.7
Silt	**Air dry**	**5.8% moisture**	**10% moisture**
1,3-DNB	<d	59.4	51.4
2,4-DNT	0.145	49.7	51.3
2,4,6-TNT	0.652	1.59	1.83
Clay	**Air dry**	**15% moisture**	**30% moisture**
1,3-DNB	<d	2.34	2.29
2,4-DNT	<d	<d	<d
2,4,6-TNT	<d	<d	<d

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Demands on chemical detection of landmines and explosives for counter-terrorism

TNT-distribution around buried mines (Draper Laboratory)

Concentrations of different substances emanating from a buried TMA-5

	Concentration / µg/kg				
Substance	surface	0-5 cm	5-10 cm	10-15 cm	under mine
2,4,6-TNT	<d	<d	9.9	7.5	873
2,4-DNT	52.3	6.3	17.0	150	5480
2-ADNT	48.8	13.6	27.5	207	3428
4-ADNT	40.8	14.2	28.8	163	2802
1,3-DNB	<d	<d	<d	<d	524

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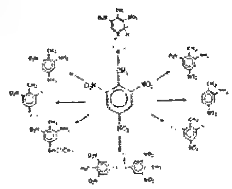
Demands on chemical detection of landmines and explosives for counter-terrorism

Aerobic TNT-biotransformation (University of Minenesota)

Depends on

- Microclimate
- Temperature
- Microorganism
- Moisture



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Demands on chemical detection of landmines and explosives for counter-terrorism

Environmental transformation products (military grade TNT)

M.E. Walsh, US Army Cold Regions research and Engineering Laboratory Hanover

Biotransformation

- 2-amino-4,6-dinitrotoluene
- 4-amino-2,6-dinitrotoluene
- 2,4-diamino-6-nitrotoluene
- 4-hydroxylamino-2,6-dinitrotoluene

Photodegradation

- 3,5-dinitrophenol
- 3,5-dinitroaniline
- 1,3,5-trinitrobenzoic acid
- 1,3,5-trinitrobenzene

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Demands on chemical detection of landmines and explosives for counter-terrorism

Vapor phase TNT-concentrations above mines (FOA, Sweden)

Analysis of the vapor and solid phase above buried mines

- Cambodia
- Bosnia-Herzegovina

Results:

In the vapor phase

- 2,4-DNT
- 2,6 DNT
- amino-DNT (Cambodia only)

were found only! TNT was detected in no vapor sample of mine affected areas

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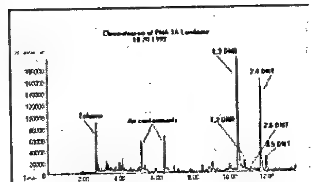
Demands on chemical detection of landmines and explosives for counter-terrorism

How smells a mine?

Canine Olfactory Detection Laboratory,

Auburn University



(Diagram: Canine Olfactory Detection Laboratory, Auburn University)

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Adsorption of TNT

- TNT adsorbs strongly on various surfaces
- basis for several bomb detectors
- Problem: luggage

What does a dog smell?

Set-up for defined TNT vapor concentrations

TNT vapor pressure approx. 7 ppb at 25 °C

TNT-concentrations above mines are much smaller.

Adjustment of defined small vapor concentrations.

Actually: 34 ppt

Which explosives are used? (from R. L. Simmons, Naval Surface Warfare Center)

- 32% of the bombings used smokeless or black powder
- 29% used simple chemical mixtures (simple gas-producing chemicals confined in a container capable of withstanding some pressure before bursting)
- 16% commercial fireworks or pyrotechnic compositions similar to those used in fireworks
- 3% were high explosives or ammonium nitrate blasting agents
- 14% could not be identified

Demands for the detection

- High sensitivity for the detection of common explosives
- Flexible for new applications

Problem

- Explosive concentration in the air decreases with increasing distance from the source
- Temperature influences the vapor concentration
- Moisture influences the vapor concentration
- Packages influences the vapor concentration
- Adsorptive behavior of explosives on different materials

What does a dog smell?

Canine Olfactory Detection Laboratory, Auburn University

Photo: Jim Johnston, Auburn University

- under consideration
- combinations of different substances
- $10^{-12} - 10^{-13}$ g explosives

How smells Nitro-glycerine based smokeless powder? Odour signature is composed of acetone, toluene and limonene.

What does a dog smell?

Canine Olfactory Detection Laboratory, Auburn University

- specificity unclear
- sensitivity very high

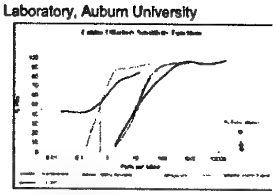
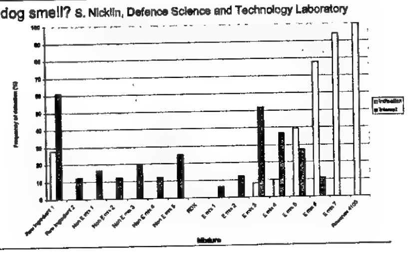


Diagram: Canine Olfactory Detection Laboratory, Auburn University

Demands on chemical detection of landmines and explosives for counter-terrorism

What does a dog smell? S. Nicklin, Defence Science and Technology Laboratory



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Demands on chemical detection of landmines and explosives for counter-terrorism

Vapor pressures of impurities

Substanz	ng/L
2,4,6-TNT	70
1,3-DNB	8140
2,4-DNT	1440
2,6-DNT	5560
RDX	0,04
HMX	0,38
PETN	0,09

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Demands on chemical detection of landmines and explosives for counter-terrorism

How smells a mine?

- Metal or plastic housing — stainless steel (painted), Polyvinyl chloride, Polystyrene
- Explosives — TNT, RDX, Picric acid
- Additives — wax, plasticizer, oil
- Impurities — 2,4-dinitrotoluene, 2,6-dinitrotoluene, 2,3,4-trinitrotoluene

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Demands on chemical detection of landmines and explosives for counter-terrorism

Smelling

distinguishes between ca. 10.000 odours
some 10 million olfactory cells
approx. 1.000 receptors/olfactory cell
specific binding for each receptor:

- alcohols, aldehydes, acids
- length of aliphatic chains
- position of functional groups
- size of molecules

Classification of odors has to be learnt.

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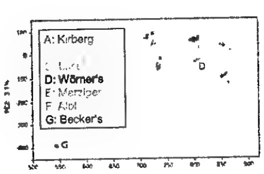
Demands on chemical detection of landmines and explosives for counter-terrorism

Pattern Recognition

- combination of unspecific sensors
- different methods e.g. 8 MOS, QMB, fluorescent polymers
- applications e.g. food industry car industry
- Classification of odors has to be learnt.



Discrimination of apple juice

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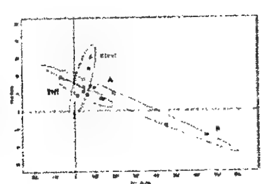
Demands on chemical detection of landmines and explosives for counter-terrorism

Simulation of smell sense

Different sensors detect different aspects (chemicals) of an explosive composition
Conventional MOS-sensors: sensitivity approx.: 100 ppb



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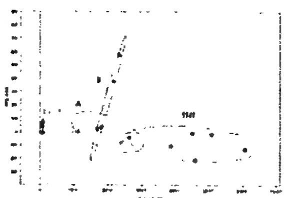
Simulation of smell sense

Combination of MOS and electrochemical sensors
Sensitivity approx.:
34 ppt (actual)



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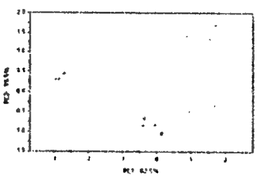
Electrochemical pattern recognition

- normal electrochemical setup
- one working electrode
- first measurement in liquid phase
- pure substances



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Comparison

lower detection limits for TNT (all systems under development)

fluorescence:	1 pg/L	0.1	ppt
antibodies:	approx.: 1 pg (after sampling)	0.1	ppt
IMS:	approx.: 50-100 pg/L	5-10	ppt
SAW:	approx.: 100 pg/L	10	ppt
conducting polymers	200-400 pg/L	20-40	ppt
electrochemical	<340 pg/L (without sampling)	<34	ppt
μ-Electron capture detector:	1 ng/L	100	ppt
Airport sniffers:	20 ng/L	2000	ppt

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Artificial Nose

- plastic model of a dog's nose based on computed tomography scans
- smell sensors placed in this set-up showed a better sensitivity

S.E. Stitzel et al.
J. Am. Chem. Soc. 125 (2003) 3684

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Basic demands on Sensors

for mine detection

- High sensitivity for TNT or better for DNT, DNB
- easy to handle
- handheld
- robust
- cheap
- all climates
- maintenance free
- low-power consumption

for counter-terrorism

- High sensitivity for various explosives
- High sensitivity for impurities
- pattern recognition
- should be flexible for new applications
- fast
- trained staff
- handheld

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Conclusions

Vapor phase detection of explosives would be a valuable tool in counter-terrorism and mine detection.

Information about chemical signature of mines and packaged explosives would stimulate the research and development of sensors.

Presumably different systems are necessary for the different applications in mine detection and counter-terrorism.

Information about the smell sense of sniffer dogs and rats will give an important input.

Sensors with high sensitivity for different aspects of explosives should be combined.

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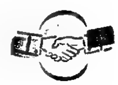
Acknowledgements



Financial support by the

Bundesamt für Wehrtechnik und Beschaffung (BWB)

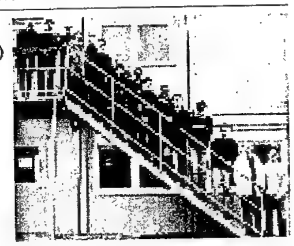
and

the Wehrwissenschaftliches Institut für Werk-, Explosiv- und Betriebsstoffe (WIWEB)

is gratefully acknowledged.

Pfinztaler Applied-Electrochemistry- (ELCH-) Team

- Batteries
- Fuel Cells
- Sensors
- Electrocatalysis



The IAEA coordinated research project on nuclear techniques for anti personnel landmine identification

Ulf ROSENGÅRD, IAEA, Austria

IAEA ACTIVITIES IN HUMANITARIAN DEMINING

Ulf Rosengård

IAEA/NAPC/Physics Section

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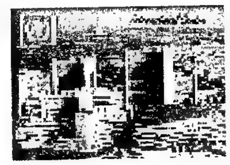
International Atomic Energy Agency (IAEA)



Founded 1957

In Vienna, Austria

134 Member States

7 Divisions

~2200 Staff

240 M$ Regular Budget

60 M$ Additional for Technical Cooperation

http://www.iaea.org/

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IAEA ORGANISATION

DG

SG NE NS NA TC MA

Applications of:
- Nuclear Instruments
- Accelerators
- Research Reactors
- Nuclear Fusion
- Meetings and CRPs
- Support to TC

HUMAN HEALTH
AGRICULTURE

PHYSICS CHEM.
- HYDROLOGY
- CHEMISTRY
- NUCL. DATA
- PHYSICS

LABORATORIES

Bled

NUCLEAR TECHNIQUES

- All explosive agents contain Nitrogen, Oxygen, Carbon and Hydrogen in known ratios.
- Nuclear methods, based on neutron irradiation, offer a possibility to non intrusively detect/identify explosive agents by measuring the above mentioned ratios.
- A REAL MINE DETECTOR
- Backscattering of neutrons indicates Hydrogen density (plastic detector).

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Elements in Explosives and Soil

Explosives in Mines

Main

TNT Trinitrotoluene $C_7H_5N_3O_6$ 1.65g/cm^3

Boosters

RDX 1,3,5, Trinitro-1,3,5-triazacyclohexane $C_3H_6N_6O_6$ 1.83g/cm^3

Tetryl 2,4,6 N-Tetranitro-N-methylaniline $C_4H_8N_5O_8$ 1.96g/cm^3

SOIL (wt%)

Oxygen	Silicon	Aluminium	Iron	Calcium	Sodium	Others
49.52	25.75	7.51	4.7	3.39	2.64	4.55

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IAEA INITIATIVES

- Advisory Group Meeting 9-12/12 1997
- Consultant's Meeting 8-10/12 1998
- Recommendation to initiate a Co-ordinated Research Project "Application of Nuclear Techniques to Anti-Personnel Landmines Identification"
- CRP started, 11 participants, first RCM in Zagreb 23-26/11 1999, St:Petersburg 11-14/9. 2001
- Regional TC-Project (TC/NA)

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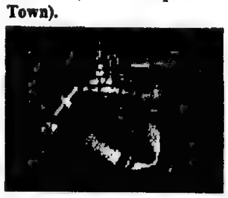
IAEA COORDINATED RESEARCH PROJECTS

- Coordinate Research in IAEA Member States
- Defined research topic
- 5-20 Members from developed as well as developing countries
- Limited financial input (~5000 US$/year to developing countries)

CRP MEMBERS

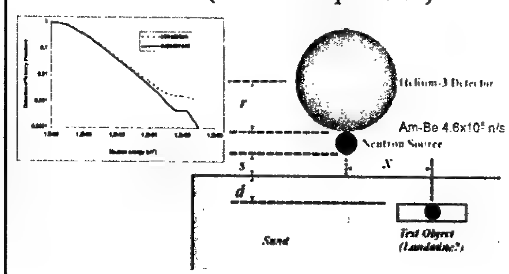
- Australia (B. Sowerby, CSIRO, γ- ray camera)
- Canada (E. Hussein, Univ. of New Brunswick, neutrons)
- Croatia (Rudjer Boskovic Inst., neutrons)
- Egypt (R. Megahid, AEC, neutrons)
- Hungary (G. Csikai, Kossuth University, neutrons)
- Italy (G. Viesti, EXPLODET, neutrons)
- The Netherlands (C. Datema, Delft, NBS **DUNBLAD**)
- Russian Fed. (A. Kutznetsov, Khlopin Institute, neutrons)
- Slovak Republic (S. Hlavac, Slovak Acad. Of Sci., neut.)
- Slovenia (Josef Stefan Institute, neutrons)
- South Africa (F. Brooks, Cape Town, NBS)
- USA (G. Vourvopoulos, W. Kentucky Univ., neutrons)

The battery-powered, hand-held HYDAD-H landmine detector. (Univ. of Cape Town).



^{3}He proportional N counter with ^{252}Cf source.

Hydrogen Density Anomaly Detector HYDAD (Univ. of Cape Town)



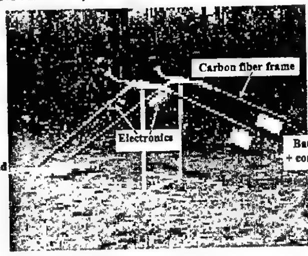
Hydrogen Density Anomaly Detector (Improvements)

- Uses a hand-held computer (Palm m515).
- Includes x and y position readout.
- Produces and updates a display map of output as $f(x,y)$.

Example of a simulated 2-stage HYDAD-H scan

Data from a simulated two-stage HYDAD-H scan, showing the distribution of "positives" obtained from: (a) the initial "fast" scan; and (b) the "follow-up" scan. Cyan and red show beep fractions of 30-70% and >70% respectively. The circles in (b) show the unknown locations of the simulated landmines, as revealed after completing the follow-up scan.

The Delft University Neutron Backscattering Landmine Detector (DUNBLAD)
C.P. Datema, V.R. Bom and C.W.E. van Eijk



Radiation dose at 1.5 meter: 0.5 μSv/h

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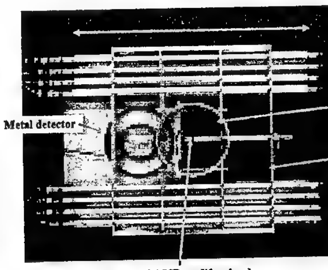
The detector head



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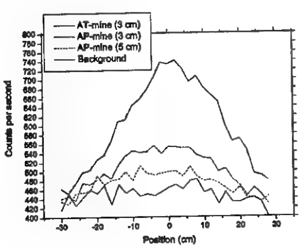
Results with DUNBLAD



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NEUTRON BACKSCATTERING

- Neutron scattering is a promising technique for the detection of landmines
- There are limitations to the technique, depending on: mine size, depth, hydrogen content, etc.water content of the soil and organic materials in the soil
- The neutron backscattering detector and metal detector are complimentary systems
- Further improvements are needed

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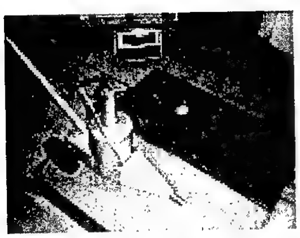
Timed Neutron Source



Khlopin Institute St:Petersburg

Timed (nanosecond) ^{252}Cf neutron source.

NaI(Tl) based (∅15cm × 10cm) gamma detector + PMT.

Prototype of the mobile device with 2 μg ^{252}Cf source with various investigated objects: TNT imitators, metallic cylinder, wet root etc.

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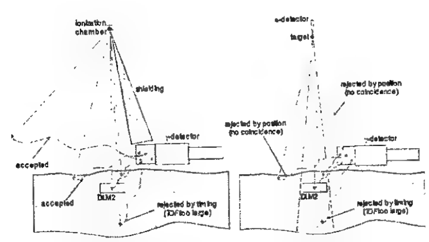
Associated Particle Technique
Advantages of a NG with multi-segment alpha-detector



^{252}Cf-based device (without position resolution)

NG-based device (with position resolution)

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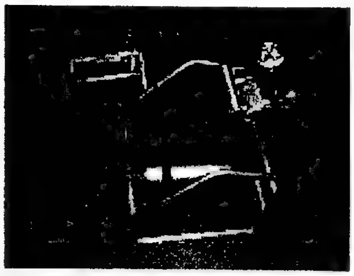
Device for explosives' detection based on a portable sealed-tube DT neutron generator with built-in nine-segment detector of accompanying α-particles.



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IAEA TECHNICAL COOPERATION (TC)

- Through Technical Cooperation projects technology can be transferred to developing Member States.
- Includes equipment, fellowships, experts and training.

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EUROPE REGIONAL TC PROJECT

- To adapt an PFTNA instrument for the identification of landmines and to demonstrate its suitability for humanitarian demining (PELAN).
- Training courses (PELAN/WKU)
- Adaptation done by a laboratory/national demining organization
- Demonstration of suitability
- If successful other regions will be considered

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Demonstration of the PELAN device in Vienna

February 2002

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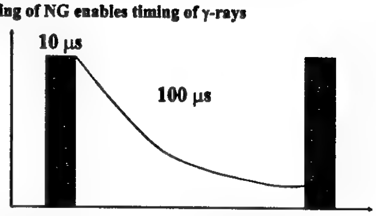
ELEMENTAL ANALYSIS BY NEUTRON IRRADIATION

- **14 MeV neutrons produced by d-t reaction**
- **Pulsing of NG enables timing of γ-rays**



n,n'γ n,p γ..... **n, γ n,α γ.....**

Prompt from C, O, ... **Delayed from N, Fe, ... Si, P (by activation)**

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IAEA training course at Western Kentucky Univ US May 2001

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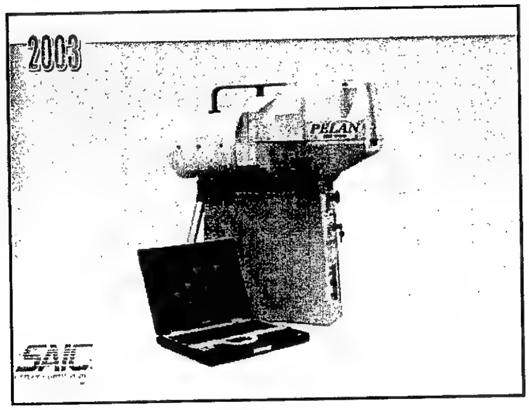
1998-02 PELAN EVALUATIONS

- CW agents : Belgium, Aberdeen PG
- **HE : Indian Head, MD, Dugway PG**
- IED,RDD,SNM : Battelle, Columbus
- **Land mines : Croatia**
- Car bombs : Albuquerque

SAIC



CONCLUSIONS

- Nuclear sensors complement conventional sensors
- Suitable as "confirmation sensors"
- Part of a multisensor device
- Handheld multisensors (Metal+GPR, Metal+NBS…..)

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Imaging techniques (optical and infrared) in landmine detection

Chris WEICKERT, CCMAT, Canada

DEFENCE R&D DÉFENSE

Canadian Research on Optical Imaging for Landmine Detection

Chris Weickert
Head/Military Engineering Section
Director/Canadian Center for Mine Action Technologies
Defence R&D Canada – Suffield

Defence R&D Canada   R et D pour la défense Canada   Canada

Canadian Landmine Detection R&D

- Canadian landmine, UXO detection R&D since 1975
- DRDC – military mine detection (US$0.70M per annum)
- CCMAT – humanitarian mine detection (US$0.35M per annum)
- DRDC Suffield is lead laboratory
- Limited budget, many technologies → look for niche areas

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Canadian Landmine Detection R&D

- Research grouped by function
  - remote minefield detection
  - close-in scanning sensors
  - confirmation sensors
- Employ many technologies to solve problem
  - electro-optical imaging
  - electromagnetic induction
  - nuclear methods
    - thermal neutron activation
    - neutron moderation imaging
    - X-ray backscatter imaging
  - advanced prodders
  - teleoperation
  - data fusion

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Hyperspectral Imaging of Landmines

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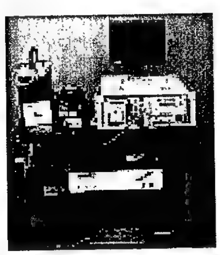
Visible/Near IR Hyperspectral Imaging

- ITRES/DRDC partners since 1989
- ITRES *casi 2* COTS systems
  - *casi 2*
  - *casi 3*
  - full software
    - geocorrection
    - detection algorithms
- VNIR problems
  - non real-time
  - slow for surface-laid
  - not reliable for buried



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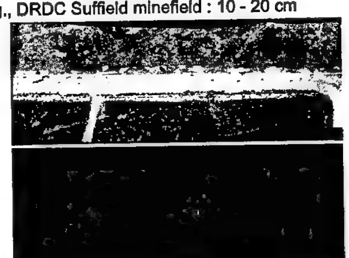
Visible/Near IR Hyperspectral Imaging (*casi*)

- Key is high spatial resolution
- e.g., DRDC Suffield minefield : 10 - 20 cm



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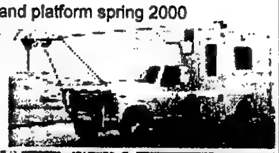
Real-time VNIR HSI

- Demonstrated on slow land platform spring 2000
- Airborne by spring 2004
- Can apply to SWIR,TIR



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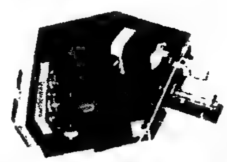
Short Wave Infrared Hyperspectral Imaging

- Algorithms simpler for surface-laid mines
- Some capability for buried mines
- ITRES *sasi* completed summer 2002
- Airborne images obtained
- Minefield tests summer 2003

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Thermal Infrared Hyperspectral Imaging

- Buried mine capability
- Few systems suitable for mine detection
- U of Hawaii AHI exception
  - not dedicated to mine detection
  - cooled MCT focal plane array
- Investigating lower cost alternative (*tasi*)
  - microbolometer FPAs
  - novel energy dispersion method
- Traditional FPA materials (VO_x) should prove concept
- Exotic FPA materials (YBCO) for final system
- To date camera with narrow band filter set (*tabi*)
  - experiments summer 2003

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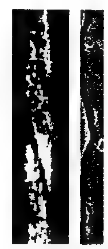
International Airborne Imager Trials - MUST 2000

- Leveraged off TTCP (AUS/CA/UK/US) spring 2000 trials to evaluate state-of-art airborne sensors for surveillance
- Added surface/buried minefields
- Airborne sensors
  - HYMAP SWIR HSI (AUS)
  - AHI TIR HSI (US)
  - JP 129 SAR (AUS)
- Results of Canadian analysis to date:
  - have only looked for mines, not other indicators
  - HYMAP: no mines detected
  - AHI: no mines detected



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Optical Tripwire Imaging

- Investigating since 1996
- Key to success – good spatial resolution
- Procam-1 CMOS sensor with dual P3 processors
  - pseudo real-time processing
- Future improvements
  - true real-time
  - better detection of broken, sagging, undulating wires
  - colour, polarization


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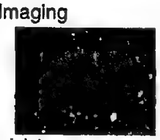
Broad Band Thermal IR Imaging

- Variable performance
  - diurnal, seasonal, environmental, soil
- Performance prediction
- Long term imaging MWIR,TIR experiment
  - fully automated, complete environmental data
  - year long data base for demining community – 06/03
  - full environmental data
  - models for simple prediction



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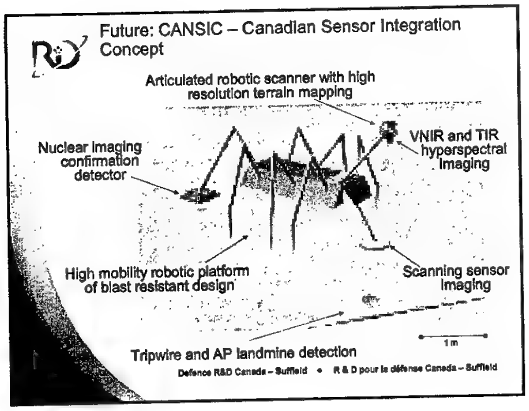
Future: CANSIC – Canadian Sensor Integration Concept
Articulated robotic scanner with high resolution terrain mapping
Nuclear imaging confirmation detector
VNIR and TIR hyperspectral imaging
High mobility robotic platform of blast resistant design
Scanning sensor imaging
1 m
Tripwire and AP landmine detection
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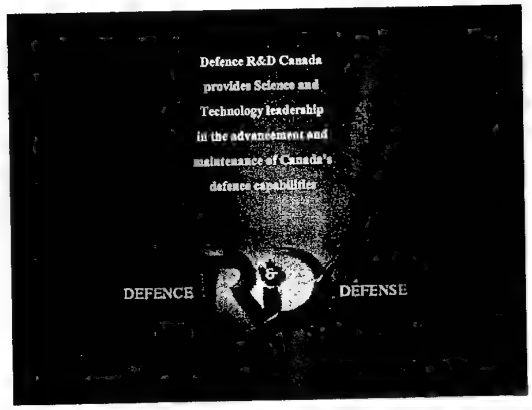
Defence R&D Canada provides Science and Technology leadership in the advancement and maintenance of Canada's defence capabilities
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